GREENHOUSE GAS EMISSION ESTIMATES AND DRAFT FORECASTS

UPDATE AND WORK IN PROGRESS

BAY AREA
AIR QUALITY
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Introduction

In November 2015, representatives from 195 countries attended the Conference of Parties in Paris (COP21 2015), a forum to address climate change on a global political level. At COP21, delegates undertook to develop binding reductions in greenhouse gas (GHG) emissions to hold global average temperatures to under 2 degrees Celsius (°C) increase over preindustrial global temperatures, a goal adopted earlier by more than 100 countries as an upper limit for avoiding the most devastating impacts of climate change. At the conference, nations established a new accord that seeks to hold warming "well below" 2°C above preindustrial temperatures.

There are many challenges to making accurate GHG emissions forecasts such as those used to estimate the GHG-reduction benefits from COP21 pledges. GHG forecasts must consider the complex connections between various energy- and fuel-related policies, links to changing economic conditions, technological advances, and uncertainties about the potential for policy overlaps and policy implementation and effectiveness (IPCC 2000). Yet, benefits to gathering what is known and putting forward our best forecasts of GHG emissions are many.[1] Previous emission forecasts have assisted in climate change analysis, including climate modeling and the assessment of impacts, adaptation, and mitigation (Meinshausen et al. 2009, IPCC 2014).

Climate researchers have recommended developing "scenarios," alternative representations of how the future might unfold, as an appropriate means by which to analyze how driving forces may influence future emission outcomes and to assess the associated uncertainties[2] (IPCC 2000). In tandem with an established emissions goal, set by previous analyses and recommendations (e.g., Meinshausen et al. 2009), GHG emissions forecasts and associated future scenarios can help assess progress and track the need for additional emission reduction measures to achieve the goal.

At COP21, the US White House presented a goal of cutting national emissions by 26% to 28% in 2025 against a 2005 baseline. As for other nations, the US expressed this goal through its Intended Nationally Determined Contribution (INDC; US INDC 2015).[3] In terms of 1990 emission levels, this INDC represents a reduction in US GHG emissions by about 16% below 1990 levels by 2025. The federal government had previously set a GHG reduction target via executive order (WhiteHouse 2015) that applies not to the US as a whole, but only to federal offices & agencies. Executive Order (EO) 13693 requires reductions in the Federal Government's GHG emissions to 40% below (fiscal year) 2008 levels by 2025 and, also by 2025, to increase the share of electricity the federal government consumes from renewable sources to 30%.

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[1] "*It is far better to foresee even without certainty than not to foresee at all*." (Poincare 1913).

[2] Alternate scenarios, and associated emissions forecasts, generally omit "surprise" or "disaster" scenarios.

[3] This pledge can likely be met without new climate laws being passed by the US Congress, but further executive action will be required and, given recent statements by the current US President, these commitments are now in question.

With the passage of Assembly Bill 32, the California Global Warming Solutions Act of 2006 (AB 32; LegInfo 2006), the State of California set GHG emission reduction targets to work toward a low-carbon future. AB32 requires statewide reductions in GHG emissions to achieve 1990 emission levels (about 427 million metric tons of CO_2 equivalent emissions per year, or 427 $MMTCO_2eq/yr$) by 2020. California EO S-3-05 (GO 2005) set targets of reducing GHG emissions to 2000 levels by 2010 and 80% below 1990 levels by 1990. The State followed this action with EO B-30-15 (GO 2015) and Senate Bill 32 (SB 32; LegInfo 2016) that set an interim target to reduce GHG emissions 40% below 1990 levels by 2030. California's Scoping Plan (ARB 2008) and Scoping Plan Update (ARB 2017a) begin to map out the policies in place and policies to reduce emissions within policy-relevant economic sectors.

While state and national commitments to reduce GHGs are critical, regional and local efforts can also contribute significantly to bridging the global emissions gap. A recent study concluded that local reduction measures, considered as a whole internationally, had an emissions reduction potential of up to two-thirds the impact of recent national policies and actions (Stockholm Environment Institute, 2014). While California has adopted aggressive and meaningful legislation to reduce GHG emissions, committed and expected policies do not achieve long-term State reduction targets (Greenblatt 2015, ARB 2016b).

The Air District, governed by a 24-member Board of Directors composed of locally elected officials from each of the nine Bay Area counties, regulates stationary sources of air pollution in the nine counties that surround San Francisco Bay: Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, southwestern Solano, and southern Sonoma counties. Through grant programs, the Air District funds projects that reduce pollutants and GHGs from mobile sources; through planning programs, the Air Districts helps reduce automobile trips and helps mitigate exposures to both stationary and mobile-source air pollution; and through outreach efforts, the Air District helps educate and inform the public about ways to reduce air pollution emissions and exposures.

The Air District has historically focused on developing policies and programs to understand and reduce air pollutants that directly impact health. In the past decade, to support GHG reduction efforts, the Air District has launched new programs and committed to protecting the global climate. For a regional agency, protecting global climate requires understanding regional GHG emissions and developing strategies—along with local, state, and national partners—to help reduce them.

The Air District has committed to a Ten-Point Work Plan (BAAQMD 2014) for understanding and reducing GHG emissions from regional sources. The Air District's commitment includes a set of GHG reduction targets (BAAQMD 2013) that align the region with targets set by the State (GO 2006, LegInfo 2006, GO 2015). GHG emissions from the Bay Area totaled about 85 MMTCO2eq in 2015 and currently account for one-fifth of the State's total GHG inventory (442 MMTCO2eq in 2014; ARB 2016a) and about 1.3% of the US GHG inventory (6,670 MMTCO2eq in 2013, USEPA 2015).[4] Meeting regional targets is therefore important to the success of state and even national climate protection efforts.

[4] These are approximate comparisons based on Air District GHG emission totals, which assume AR5 global warming potentials and ARB and US EPA totals, which use AR4.

Moreover, methods and policies developed at the Air District may serve as a useful example to be adapted by other regional agencies.

In addition to setting regional GHG targets, the Air District's Ten-Point Work Plan includes a commitment to improve GHG emission inventories and forecasts. Inventories and forecasts help guide the development of new GHG reduction policies, especially to the extent that forecasts include accurate predictions of how existing committed policies will affect future emission levels. Previous efforts to inventory the Bay Area region's GHG emissions included only business as usual (BAU) forecasts. To understand the level of effort needed to meet regional GHG targets, given the commitments made at the state level, it is necessary to forecast emissions into the future with committed policies and with likely policies in place to develop regional and local strategies.

This report describes the Air District's initial draft efforts to include adopted and expected policies to improve the accuracy of regional GHG forecasts. This report describes preliminary work to forecast trends in GHG emissions in the San Francisco Bay region. Many policies—at local, state, and federal levels—aim to limit GHG emissions in the future. This draft strives to reflect these policies in the GHG forecasts to elucidate where more work is needed to meet adopted regional GHG reduction targets. It is a starting point upon which more detailed assessments can build.[5]

GHG emission inventory estimates and forecasts developed within this report will be used to inform the Air District's policy and program development efforts. These efforts are embedded as a series of "Gap Analysis" reports, which examine the anticipated "gaps" between target GHG emission reductions and emissions forecasts developed by this report. Emissions are disaggregated into economic sectors, similar to sectors in California's Scoping Plan Update (ARB 2014, ARB 2017a), to support the Gap Analysis reports. The work of the Gap Analyses will then be to identify feasible regional measures to supplement GHG reductions within sectors, as needed, to meet regional goals and, ultimately to help California reach its 2050 target and to help move global GHG reductions beyond COP21 pledges.

As discussed in the Methods section below, the GHG forecasts developed in this report rely on several sources. The first source was the Air District's previous estimates of GHG emissions for the two decades between 1990 and 2010 (BAAQMD 2015). Updates to 2015 have been developed for stationary sources permitted by the Air District to reflect more current conditions. Specifically, draft updates to 2015 GHG emissions estimates were developed for oil refineries, cement plants, and power plants.

A second source was a modified version of the CALGAPS model developed at the Lawrence Berkeley National Laboratory (LBNL) under contract to the California Air Resource Board (ARB) to forecast GHGs at the state level to 2050 (Greenblatt 2015). As described in the Methods section, Greenblatt developed a regional sub-model ("BA-CALGAPS") that incorporates both committed and expected statewide policies to forecast GHG emissions in the Bay Area. These scenarios are briefly summarized in this report but were developed and explained more fully in Greenblatt (2015) and in Appendix A.

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[5] "*If you have to forecast, forecast often.*" (Fiedler 1977)

A third source of information was ARB's recently updated Vision scenario modeling tool, used to support the 2016 Mobile Source Strategy and to enhance the ARB's ability to conduct analyses on the transportation system for informing policy decision-making. We used the Vision 2.1 Passenger Vehicle Module and Heavy-Duty Truck Module (ARB 2017b) to represent recent updates to GHGs from on-road, light- and medium-duty vehicles, an important and rapidly evolving emissions source category.

A fourth source of information applied in developing Bay Area GHG forecasts was output from the PATHWAYS model developed by E3, with support from LBNL, for California (Williams et al. 2012, Mahone et al. 2015). While the PATHWAYS model provides economy-wide and sector-specific forecasts of GHG emissions for several sectors described in the State's Scoping Plan, we relied on the PATHWAYS forecasts only for Industrial emissions.

In some cases, where regional forecasts were unavailable but statewide forecasts did not match Air District expectations of future Bay Area growth, in-house forecasts were developed. These in-house forecasts, which represent a fifth source of information, were developed for the Agriculture and Farming sector and the Recycling and Waste sector. See Table 2 through Table 8 in the Methods section below for more details.

Based on these five information sources, draft GHG forecasts to 2050 were developed for the Bay Area. Preliminary results and their implications are described in the Results section. These preliminary results are a first step toward a more fully developed set of GHG forecasts. Plans for updates and methodological changes to improve GHG predictions are outlined in the Next Steps section.

Methods

Overview

The Air District reported its first regional GHG emissions inventory in 2007, for base year 2002 (BY 2002). Since then, it has generally issued updates on a triennial basis. The most recent update, completed in 2015 for BY 2011 (BAAQMD 2015), included BAU GHG emission forecasts to 2030. The BY 2011 report identified the need to extend forecasts to 2050 and to represent GHG-reduction rules and policies already in place.

This report presents a first step toward developing an extended Bay Area GHG emissions forecast that includes existing and anticipated policies. Other changes made in this report, relative to previous reports, include: updates to the global warming potential (GWP) for non-CO_2 gases; emission estimates and reporting for economic sectors, similar to those used for the State's Scoping Plan Update (ARB 2014); and updates to the GHG emission calculations for industrial sources and power plants for years 2010–2015.

While the changes in methodology described in this report are a step forward relative to earlier Air District GHG emissions estimates and forecasts, the reader should be advised that the Air District still considers the current estimates and forecasts to be a draft, for reasons outlined in the Caveats and Assumptions section below.

Base Year Greenhouse Gas Emission Estimates

To develop draft forecasts of GHG levels in the Bay Area, we started with a base year 2011 (BY 2011) Air District GHG emissions inventory, which had been developed and documented previously (BAAQMD 2015). For the BY 2011 emissions estimates, GHG sources were broadly categorized as stationary or mobile sources. Stationary sources were further classified as point sources or area sources. Point sources are typically facilities with permits issued by the Air District, including large industrial sources, such as power plants and refineries, and smaller sources, such as process boilers and backup generators. Area sources are typically small sources individually but can contribute significantly because there are many of them.

To estimate historical emissions from point sources, the Air District maintains a database with information on operations and emission characteristics for nearly 4,000 facilities, which include roughly 25,000 different sources, throughout the Bay Area. Activity data on the sources are collected at the process level from each facility and are updated regularly as part of permit renewal. The GHG emissions from these sources are generally calculated by multiplying activity data by emission factors for each greenhouse gas.

To estimate historical emissions from area sources requires a combination of statewide data (such as construction data) and locally derived information (such as airport activity). Such information is often linked to population or employment statistics, to estimate activity and standardized emission factors to estimate emissions per unit activity. As for point sources, the GHG emissions from area sources are calculated by multiplying activity data by emission factors for each greenhouse gas.

The mobile-source category is further subdivided into: (a) on-road motor vehicles; (b) off-road mobile sources. Examples of on-road motor vehicles are cars, trucks, buses, and motorcycles. Off-road mobile sources include boats, ships, trains, aircraft, and garden, farm and construction equipment.

Historical GHG emissions (1990–2010) from on-road motor vehicles were calculated using the California Air Resources Board's (ARB's) statewide model for on-road motor vehicles, EMFAC. At the time the BY 2011 GHG emission inventory was compiled, the latest available version of EMFAC was EMFAC2011. For this work, we considered replacing on-road emissions from EMFAC2011 with the estimates from the more recent EMFAC2014. However, EMFAC2014 does not report emissions prior to 2000. Additional analysis will be required to extend the EMFAC2014 emission estimates back to 1990.[6] The EMFAC model was provided with vehicle miles travelled (VMT) and other activity data by county from regional transportation plans.

Historical GHG emissions (1990–2010) from off-road mobile sources (excluding ships, trains, and aircrafts) were estimated using ARB's OFFROAD2007 model. Aircraft emissions are calculated for air travel within the Air District boundaries. GHG emissions for ships are calculated for ship travel within 100 miles of the San Francisco coastline. More details on GHG emission calculations, including activity estimates and emission factors for various source categories and fuels types have been described in more detail in the BY 2011 GHG report (BAAQMD 2015).

Not included in the BY 2011 GHG emissions inventory and, likewise, not included in this report are GHG emissions from natural and working lands. Vegetation and soils can sequester carbon from the atmosphere, reducing the magnitude of climate change. But fires, deforestation, and soils disruption can release sequestered carbon and produce a net carbon source. A recent study of California's forests and rangelands (excluding soils) estimated a net carbon release of about 14 Mt C/year between 2001 and 2008 (Battles et al. 2013).[7] Future Air District work will apply a stock-change approach similar to that used in Battles et al. (2013) to the Bay Area to help understand how development, forest, and agricultural practices contribute to or mitigate GHG emissions.

Updated Global Warming Potentials

Different types of GHGs—for example, CO_2, methane (CH_4), and nitrous oxide (N_2O)—have varying potentials to absorb infrared radiation and heat the atmosphere. When summing or comparing GHG emissions, the Intergovernmental Panel on Climate Change (IPCC) recommends using global warming potentials (GWPs) to represent a mixture of GHGs in terms of its CO_2 equivalence (CO_2eq). GWPs provide a measure of the forcing impacts of a particular greenhouse gas over a period of time *relative* to the forcing from CO_2.[8] Given a timeframe of interest (such as the next 100 years, or the next 20 years), GWP values allow us to compare the impacts of emissions of different gases because they normalize GHGs in terms of their potential to warm the atmosphere. As more is learned about how GHGs are

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[6] Given the substantial reductions in emissions from on-road motor vehicles that have resulted from State regulations since 1990, the State is missing an important opportunity to document its own successful programs by not reporting emissions prior to 2000 in the latest version of EMFAC.

[7] This translates to a CO_2 release of about 51 MMT CO_2/year = 14 MtC /year * (44 g CO_2/12 g C), or more than 10% of the State's 2012 GHG emissions inventory (460 MMTCO2eq/year).

[8] The GWP for CO_2 is equal to one (1).

likely to heat the atmosphere, the IPCC issues updates to GWPs in its Assessment Reports. The science is evolving, so releasing improved estimates of GWPs is consistent with sound scientific reporting practice.

One of the updates made in this report relative to previous Air District reports on GHG emissions (BAAQMD 2015) is that here we applied the latest GWPs from the IPCC. This report used GWPs from IPCC's 5th Assessment Report (AR5, IPCC 2013); whereas, earlier reports used GWPs from the Second Assessment Report (SAR, IPCC 1996).

Using the latest science to report emissions will likely result in better policy decisions. However, the updates to GWP values published by the IPCC can lead to confusion. New releases of GWPs create the potential for inconsistent reporting among reporting agencies. Moreover, they change emissions inventories for reasons that are unrelated to changes in activities or technologies. Appendix B provides background on GWPs, details options considered in selecting GWPs, and discusses, in more detail than provided in this section, and the reasons for and implications of adopting the latest GWPs from the IPCC.

In addition to updating GWP values, IPCC's AR5 also provides GWP values that account for "carbon-climate feedback effects." The feedback effects account for the diminishing ability of oceans and soils to absorb carbon dioxide as the climate warms. They also account for the production of additional CO_2 that may be produced as GHGs are oxidized in the atmosphere. Appendix B and the IPCC's AR5 (IPCC 2013) provide more discussion of feedback effects. This report used GWPs with feedback effects because the IPCC concluded that including them likely gives a more accurate estimate of climate impacts from short-lived, high-GWP GHGs, such methane.

An added consideration when applying GWPs is the time horizon for which global warming is considered. Almost everyone uses a 100-year time horizon and reports GHGs using 100-year GWP values. However, the IPCC also provides 20-year GWPs. The 20-year GWPs are useful for examining near-term climate impacts and give more weight to compounds, such as methane, with atmospheric lifetimes that are much shorter than 100 years. For some policy analyses, a 20-year time horizon is more appropriate than a 100-year horizon. For example, to reduce global warming as soon as possible, we seek measures with meaningful short-term benefits while we work to develop longer-term policies. In this report, we generally use 100-year GWPs but, for some analyses, we also report GHG emissions using 20-year GWPs.

Table 1, below, lists the GWPs (100-year and 20-year) used in this report.

Table 1. GWP Values on a 100-year horizon (GWP_{100}) and on a 20-year (GWP_{20}) horizon from the IPCC's AR5.

Pollutant	GWP_{100}	GWP_{20}
CO_2	1	1
CH_4[a]	34	86
N_2O[a]	298	268
SF_6	23500	17500
CF_4 (PFC-14)	7350	4950
C_2F_6 (PFC-116)	11100	8210
C_3F_8 (PFC-218)	8900	6640
C_4F_8 (PFC-318)	9540	7110
HFC-125	3170	6090
HFC-134a	1550	3790
HFC-143a[a]	4800	6940
HFC-152a	138	506
HFC-227ea	3350	5360
HFC-236fa	8060	6940
HFC-245fa	858	2920
HFC-365mfc	804	2660
HFC-32	677	2430
HFC-43-10mee	1650	4310
HFC-23	12400	10800
HCFC-22	1760	5280
NF_3	16100	12800
HFCs[b]	1300	1300
PFCs[b]	6500	6500
HFC+PFC[c]	9628	7199
Other PFC[d]	9301	9301

a. Including carbon-climate feedbacks. Future work will use carbon-climate feedbacks for all pollutants for which they are available in the AR5 Supplementary Materials.
b. Grouped compounds with GWPs as defined in the BY 2011 GHG report (BAAQMD 2015) using AR2. Future work will represent GWPs for grouped compounds with GWPs for individual pollutants using AR5.
c. Semi-conductor composite of HFC and PFC compounds using AR5 GWPs. Future work will represent this composite as individual pollutants.
d. Other PFCs as defined by the California Air Resources Board (ARB 8th Edition area source emissions). Future work will represent GWPs for grouped compound with GWPs for individual pollutants using AR5.

The adoption of AR5 GWP values has been fairly slow, as national and international agencies emphasize consistency among reporting parties' inventories over more up-to-date representation. While eventually, it is likely that that the adoption of AR5 GWPs will become best practice, for now major players are sticking to the older the IPCC's 4th Assessment Report (AR4; IPCC 2007) GWPs to be consistent with each other. For example, the 2007 AR4 GWPs have been adopted fairly recently by ARB, Environmental Protection Agency (USEPA), and the United Nations Framework Convention on Climate Change (UNFCCC).

For the Air District, tolerating a GWP-related discrepancy between, for example, how the Air District reports and how ARB reports GHGs seems worth the benefit of adopting methods that will more accurately reflect the impacts of non-CO_2 compounds. Better representation of the climate impacts of non-CO_2 compounds will help Air District staff develop a better understanding of the regional GHG inventory and develop more informed regulations and policies to reduce GHGs. See Appendix A for more details on the application of the AR5 GWPs and the Air District's reasons for applying them.

Inventory Sectors

The emissions inventory *categories* reported in the BY 2011 emissions inventory were regrouped to be consistent with ARB Scoping Plan reports. The Scoping Plan Update (ARB 2014) refers to the *economic sectors* listed below:

- Transportation
- Cap-and-Trade Regulation
- Energy
- Green Buildings
- Water
- Waste Management
- Agriculture
- Short-Lived Climate Pollutants
- Natural and Working Lands

The sectors used in this report, while based on those in the Scoping Plan Update, differ in two important ways. First, as mentioned above, we have not yet produced emissions estimates from natural and working lands. Second, we have narrowed the definition of the Scoping Plan sectors to avoid having overlap (double-counting) of emissions across sectors. The emissions inventory sectors applied in this report include the following:

- Transportation
- Industrial
- Electricity and Cogeneration
- Commercial and Residential
- Recycling and Waste
- Agriculture and Farming
- High GWP Gases

The application of sectors and subsectors to the development of GHG forecasts is discussed in more detail in Table 2 through Table 8 in the Forecast Methods section.

Note that the Commercial and Residential sector includes only direct emissions (mostly combustion emissions from fuel use) and not indirect emissions from electrical energy use. GHG emissions associated with electrical energy use are included in the Electricity and Cogeneration sector. So, for example, electrical energy used to pump water is included in the Electricity and Cogeneration sector and cogeneration at industrial facilities, such as at refineries, is also included in this sector.

Indirect GHG emissions associated with electrical energy used within the Bay Area but generated elsewhere is also counted within the Electricity and Cogeneration sector. However, GHG emissions associated with exported waste generated within the Bay Area are not counted in the Recycling and Waste sector. High GWP gases are used and emitted in several sectors; however, their GHG contributions are reported only within the High GWP Gases sector.

Forecast Methods

For the two decades spanning 1990–2010, GHG emission estimates reported here are consistent with the Air District's BY 2011 estimates GHG emissions reports (BAAQMD 2015), with the exception of minor updates to correct previous reporting errors.

Estimates for major stationary-source categories—including refineries, a larger cement plant, and power plants—for the years 2010–2015 have been updated using GHG estimates reported by facilities to the ARB under its Greenhouse Gas Reporting Program. Forecasting for these sources, therefore, begins in 2015. For other emission categories, forecasting begins in 2010.

In general, these inventory projections have been designed to be consistent and compatible with the models and assumptions underlying the economy-wide "Reference" scenario set forth by the ARB in its July 2016 Draft Scoping Plan Concept Paper (ARB 2016b). For the years 2010–2015, GHG emissions from mobile sources have been forecast using ARB's Vision model (ARB 2017b). Most of the remaining GHG emission forecasts rely on output of the BA-CALGAPS model, developed at the Lawrence Berkeley National Laboratory (LBNL) under contract to the ARB (Greenblatt 2013). Greenblatt developed several forecast scenarios for California: a "counter-factual" base-case, a scenario with only committed policies for reducing GHGs, and a scenario with both committed and expected policies for reducing GHGs. These scenarios are described in the BA-CALGAPS documentation by Greenblatt (2013, 2015).

Forecasts for GHG emissions from industrial sources, including those covered by Cap-and-Trade regulation, are based on output of the PATHWAYS model developed by E3 with support from LBNL (Williams et al. 2012, Mahone et al. 2015) for the State of California. The PATHWAYS model provides forecasts for large industrial sectors covered under the State's Cap & Trade program, while BA-CALGAPS explicitly does not.

While the BA-CALGAPS does include emission forecasts for both light- and heavy-duty, on-road vehicles, to incorporate recent updates for on-road passenger vehicles, we applied forecasts from the ARB's Vision scenario modeling tool, used to support the 2016 Mobile

Source Strategy. We used output from the Vision 2.1 Passenger Vehicle Module (ARB 2016c) and Vision 2.1 Heavy-Duty Vehicle Module (ARB 2017) to represent recent updates to GHGs from all on-road vehicles with the exception of motorcycles and motorhomes. (These vehicles account for a very small portion of the on-road vehicle GHG emissions; we used EMFAC trends to forecast these emissions.)

BA-CALGAPS and PATHWAYS models were developed to forecast California-wide emission totals, but here we have applied them specifically to the Bay Area. This may be an acceptable approach where statewide policies apply in a roughly uniform way. For some sectors, or subsectors, where available statewide forecasts did not match Air District expectations of future growth, we developed and applied modified forecasts. Table 2 through Table 8 show policies applied in the growth profiles applied for each sector and list policies included, or represented, in the forecast method applied.

Table 2. Transportation sector forecasts, policies, and comments.

Sector	Subsectors	Forecast	Policies Included and Notes
Transportation	Passenger Cars & Trucks (< 8,500 lbs.) and Buses	2010–2050: VISION2.1-Passenger (ARB 2017b)	• Pavley + other LDV standards • Zero-Emission Vehicles (ZEVs) Rule • ZEV Urban Bus sale projections • Sustainable Communities Strategy (SCS) • Low-Carbon Fuel Standard (LCFS) • Renewable-Energy Hydrogen (SB 1505) • Petroleum Displacement with Biofuels (AB 2076, AB 1007)
	Heavy Duty Trucks (> 8,500 lbs)	2010–2050: VISION2.1-Heavy-Duty Vehicles (ARB 2017b)	• USEPA GHG Phase 2 standards implementation beginning 2018 • Integration of Zero Emission delivery trucks starting 2020 • System-wide HDV Efficiency: 9.5% decrease in VMT • Petroleum Displacement with Biofuels (AB 2076, AB 1007)
	Motorhomes & Motorcycles	2010–2050: EMFAC2014	• EMFAC2014 (Bay Area specific)
	Ships & Boats, Locomotives, Industrial Equipment, Aviation	2010–2050: BA-CALGAPS (Appendix A)	• Shore Power for Ocean-Going Vessels • High-Speed Rail

Table 3. Industrial sector forecasts, policies, and comments.

Sector	Subsectors	Forecasts	Policies Included and Notes
Industrial	Oil Refineries	2010–2015: ARB GHGRP data 2015–2050: PATHWAYS v2015-04 (Mahone et al. 2015)	• PATHWAYS Refining profile • Does not include combustion of any refined fuels exported outside the Bay Area • 2.3 MMTCO$_2$eq of cogeneration at refining facilities is tabulated under Electricity + Cogeneration (Table 4)
	General Fuel Usage	2010–2050: PATHWAYS v2015-04 (Mahone et al. 2015)	• PATHWAYS Industrial profile • Almost entirely natural gas, post-2015
	Cement Plants	2010–2015: ARB GHGRP data 2015–2050: BAAQMD (This report)	• Baseline = PATHWAYS Industrial • Also: 9% non-energy GHG reduction (fly ash substitution)
	Natural gas distribution losses	2010–2050: BA-CALGAPS (Greenblatt 2013, 2015) (Appendix A)	• Follows Commercial + Residential Fuel forecast (see Table 5)

Table 4. Electricity and Cogeneration sector forecasts, policies, and comments.

Sector	Subsectors	Forecasts	Policies Included and Notes
Electricity + Cogeneration	Electricity Generation + Electricity Imports	2010–2015: ARB GHGRP data 2015–2050: BA-CALGAPS (Greenblatt 2013, 2015) (Appendix A)	• Renewable Portfolio Standard (RPS) + local actions = 54% renewables by 2020 • Distributed Generation Photovoltaic (DGPV): 5000 GWh/yr; % grows with RPS • Zero Net Energy (ZNE): 100% of new residential construction by 2020; 100% of new commercial construction by 2030 • Improved new construction and retrofit efficiencies • Improved Lighting Efficiency • 46% per capita water savings by 2020
	Cogeneration	2010–2015: ARB GHGRP data 2015–2050: PATHWAYS v2015-04 (Mahone et al. 2015)	• PATHWAYS Industrial profile • Cogeneration at refining facilities is tabulated here

Table 5. Commercial and Residential sector forecasts, policies, and comments.

Sector	Subsectors	Forecasts	Policies Included and Notes
Commercial + Residential	Commercial Fuel Use + Residential Fuel Use	2010–2050: BA-CALGAPS (Greenblatt 2013, 2015) (Appendix A)	• Efficiency: 2.9%/yr retrofit rate, 20% efficiency gain by 2030, 50% by 2030 (all residential & commercial buildings) • Electrification of new construction: 25% in 2020, 60% in 2030, 100% in 2050; slightly lower for retrofits • Zero Net Energy (ZNE): 100% of new residential construction by 2020; 100% of new commercial construction by 2030 • Note: Direct combustion of natural gas at commercial and residential buildings only. GHGs attributable to grid-based electricity are tabulated under “Electricity + Cogeneration” (Table 4)

Table 6. Recycling and Waste sector forecasts, policies, and comments.

Sector	Subsectors	Forecasts	Policies Included and Notes
Recycling + Waste	Landfills, Composting, & Other Waste Mgmt	BAAQMD (This report)	• Baseline = ABAG (Plan Bay Area 2040) “Population” forecast • AB 341: by 2020, methane (CH4) emissions = 90% of 2010 level. By 2050, 30% of the 2010 level. • SB 1383: additional 14% reduction in landfill GHGs, 2020–2030. • Does not include emissions from waste exported outside Bay Area
	Wastewater Treatment (Domestic & Commercial)	BAAQMD (This report)	• SB 1383 requires CARB to approve and begin implementing a plan reducing 40% of methane emissions from Wastewater Treatment Facilities, 2020–2030 • SB 1122 directs CPUC to require the State’s investor-owned utilities to develop and offer contracts to obtain electricity from biogas facilities

Table 7. Agriculture and Farming sector forecasts, policies, and comments.

Sector	Subsectors	Forecasts	Policies Included and Notes
Agriculture + Farming	Animal Waste, Soil Management, Agricultural Equipment, and Biomass Burning	Association of Bay Area Governments (ABAG) 2013	• "Agriculture and Natural Resources" labor forecast • Reductions may be realized under SB 1383 (State-wide reduction of Dairy and Livestock Methane emissions by up to 40% from 2013 levels in 2030); however, Bay Area operations are typically small

Table 8. High GWP sector forecasts, policies, and comments.

Sector	Subsectors	Forecasts	Policies Included and Notes
High GWP Gases	HFC-134a, other HFCs and PFCs	BA-CALGAPS (Greenblatt 2013, 2015) (Appendix A)	• HFC phase-out, conformant to Kigali Amendment to Montreal Protocol: 50% of HFC supply curtailed by 2035; 100% by 2050 • 15-year lag between modeled supply reductions and modeled emission reductions

Local Actions

Although it was not possible to allocate "local action" reductions to specific economic sectors, our best estimate is that an additional savings of 1.5 $MMTCO_2eq$ will be realized in 2020 due to local actions.

Caveats and Assumptions

Reviewers and users of information contained in this report should be aware of the following caveats and assumptions:

- The Air District is conducting an audit of historical emissions (1990–2015), including GHG emissions, as part of the development of a Quality Assurance Project Plan (QAPP) for the agency's emissions inventory reporting. The audit and QAPP may result in changes to the historical GHG emissions reported here.
- The Air District is actively engaged in studies to evaluate the regional methane emissions inventory. Preliminary work suggests that we are missing sources of methane emissions, significantly under-reporting known sources, or both. Reconciliation of current inventories against recent findings may result in changes to GHG emissions reported here.

- This report represents the Air District's first effort on developing a regional GHG emissions forecast that incorporates national, state, and local reduction GHG reduction policies. Subsequent efforts, informed by and building upon this initial effort, will likely result in changes to our GHG forecasts.
- For some sectors, the regional forecasts reported here were derived from statewide forecasts. Future efforts will aim to adapt these forecasts to the Bay Area sources to a greater degree. More specificity of forecasts to individual sources within sectors will be more useful for informing policy development discussions.
- Future efforts will update forecasts to incorporate more policies adopted after mid-2016 (the date of the development of BA-CALGAPS). For example, the final requirements of SB 350, adopted in 2015, may not have been accurately foreseen for some sectors.
- Major industrial disasters (such as Aliso Canyon) and natural disasters are not included. Major technological changes are also not included.

Results

Overview

Figure 1 shows estimated historical and projected changes in Bay Area GHG emissions over time, apportioned to seven economic sectors. This regional-scale inventory shows expected future emissions of GHGs within the Bay Area. This section provides an overview of the Air District's draft forecast results for regional GHG emissions.

Figure 1 shows that GHG emissions grew by more than 25% between 1990 and 2014, the approximate peak in this forecast. This growth was driven by all sectors except the Recycling and Waste sector, which dropped sharply, and the Agriculture and Farming sector, which remained nearly constant. Forecasts show significant future reductions in the Transportation, Electricity and Cogeneration, and High GWP Gases sectors and modest or no significant reductions in the other sectors. These forecast GHG reductions occur in spite of predicted continued population and economic growth; however, they are not sufficient to meet the 2020 GHG goal.

In 2015, the Bay Area's GHG emissions total about 85 million metric tons (Figure 2). The seven sectors include transportation (on-road and off-road sources; about 41%); industrial, mostly refineries and a cement plant (about 26%); electricity and cogeneration, including both direct combustion and electricity imports (about 14%); and commercial and residential, mostly fuel combustion for heating and cooking (about 11%). The remainder is from high GWP gases (about 4%), recycling and waste facilities (about 3%), and Agriculture and Farming operations (about 1%).

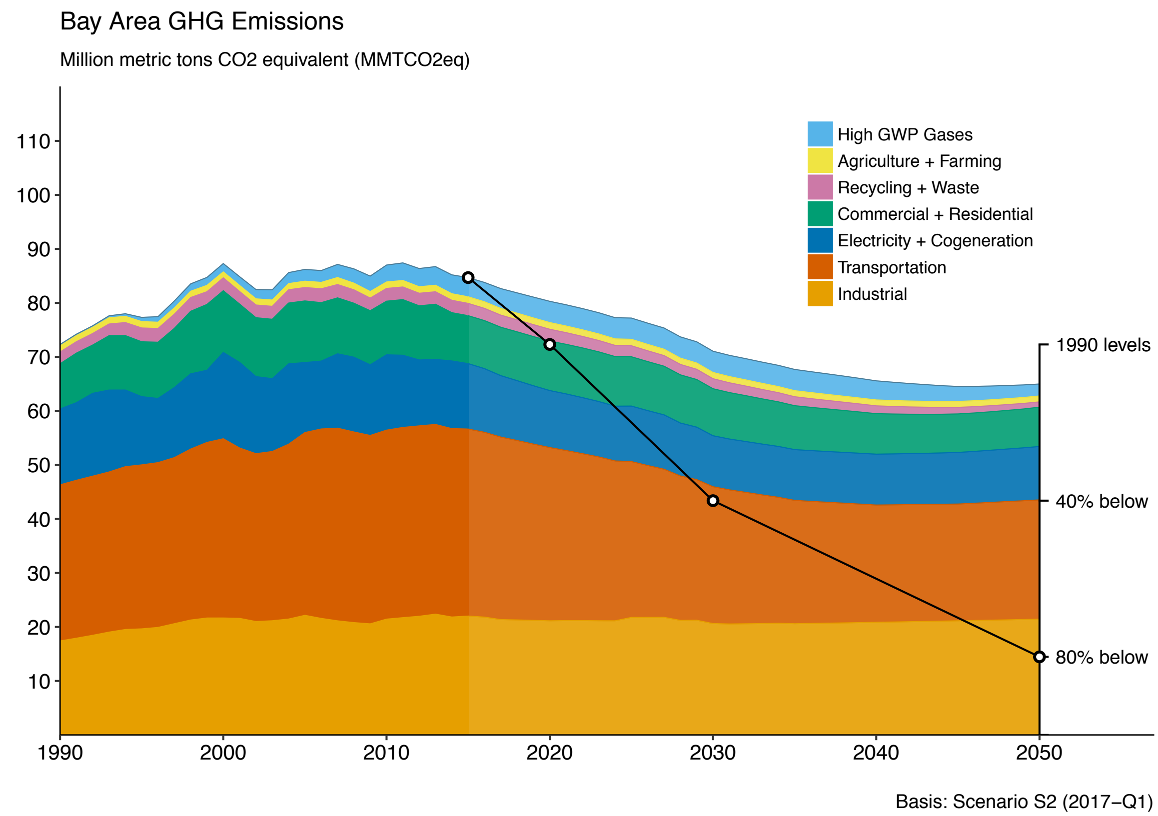

Figure 1. Bay Area GHG emissions, by sector, reported in million metric tons CO_2 equivalent (left axis, using 100-year GWPs) and relative to 1990 levels (right axis). A "glide path", starting in year 2015 at current levels, is depicted as a series of black line segments connected by circles. The circles represent goals of 0%, 40%, and 80% below 1990 levels in 2020, 2030, and 2050, respectively. The glide path can be compared with the projections of expected GHG emissions, depicted as lighter-colored ribbons. These projections assume a scenario in which currently committed and expected regulations and policies to reduce GHGs are implemented (see Tables 2–8). Given this, Bay Area GHG emissions are projected to decrease gradually from 2015 to 2040, and to level off between 2040–2050. Projected GHG emissions are not likely to meet near-term goals for the Bay Area, and will almost certainly fail to meet a 2050 goal of 80% below 1990 levels within the Bay Area.

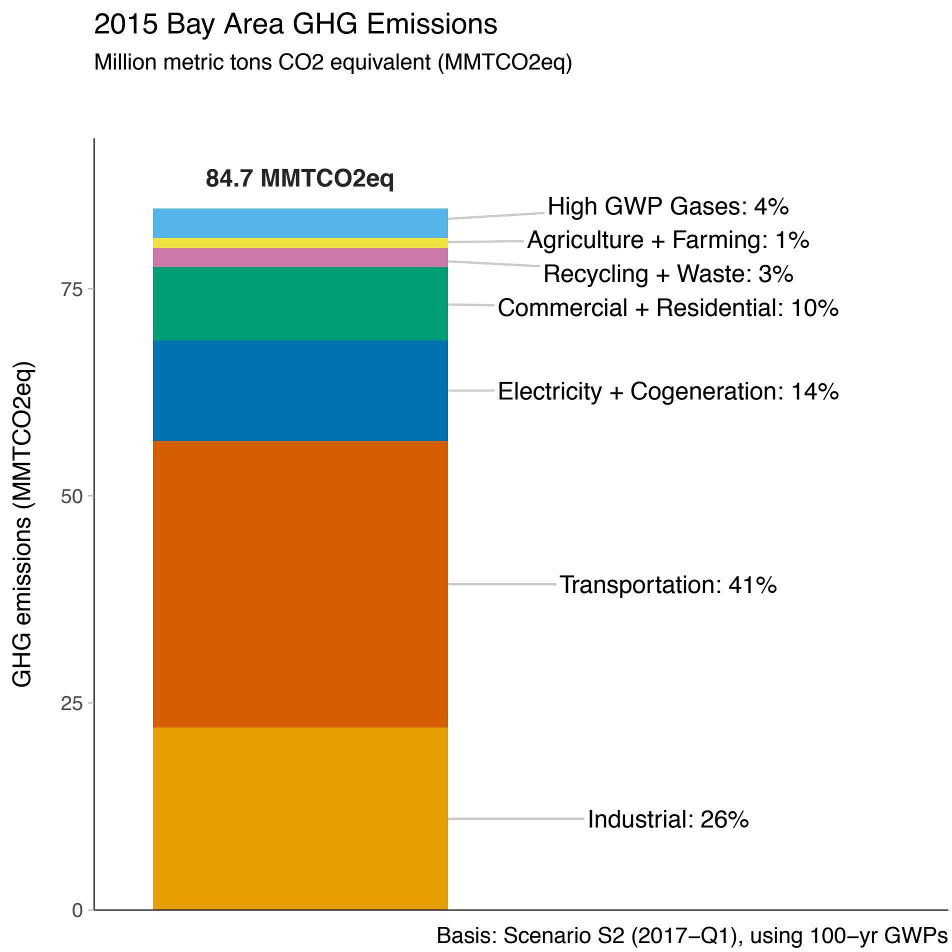

*Figure 2. Bay Area GHG emissions, by sector, with committed and expected policies ≈ **85 million metric tons CO_2 equivalent ($MMTCO_2eq$)** in 2015. The Transportation sector, which includes both on-road and off-road sources, is the largest sector (41%). It is followed by the industrial sector (26%), composed mostly of GHG emissions from combustion and related processes at refineries and other industrial facilities, including a cement plant. Next is the Electricity and Cogeneration sector (14%), which accounts for direct combustion at power plants, cogeneration (including cogeneration at industrial facilities), and electricity imports. GHG emissions from the Commercial and Residential sector (11%) are due mainly to the on-site combustion of natural gas, which is used to heat buildings, water, or other materials. The remainder is accounted for by Recycling and Waste (3%), High GWP Gases (4%), and Agriculture and Farming (1%). CO_2 equivalents assume 100-year GWPs with carbon-climate feedbacks.*

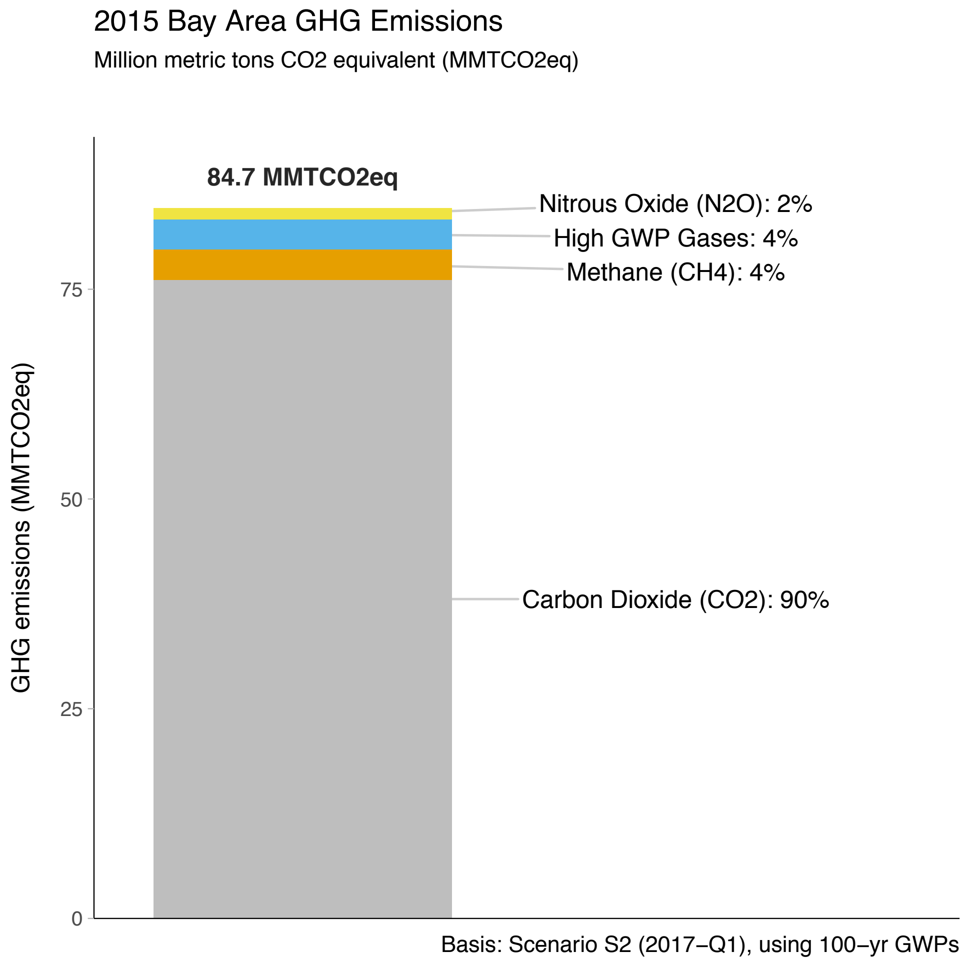

Figure 3. *Bay Area GHG emissions (CO_2 equivalents) in 2015, using* ***100-year GWPs*** *(with carbon-climate feedbacks). Of the total (85 million metric tons), most is from CO_2 (90%). The remainder is composed of methane (4%), high GWP gases (4%), and nitrous oxide (2%).*

Throughout this report, CO_2 equivalents are generally reported using 100-year GWPs with carbon-climate feedbacks (IPCC 2013). Using 100-year GWPs, 2015 Bay Area GHG emissions total about 85 million metric tons. Most of this (90%) is carbon dioxide (Figure 3); the remainder is methane (4%), high GWP gases (4%), and nitrous oxide (2%).

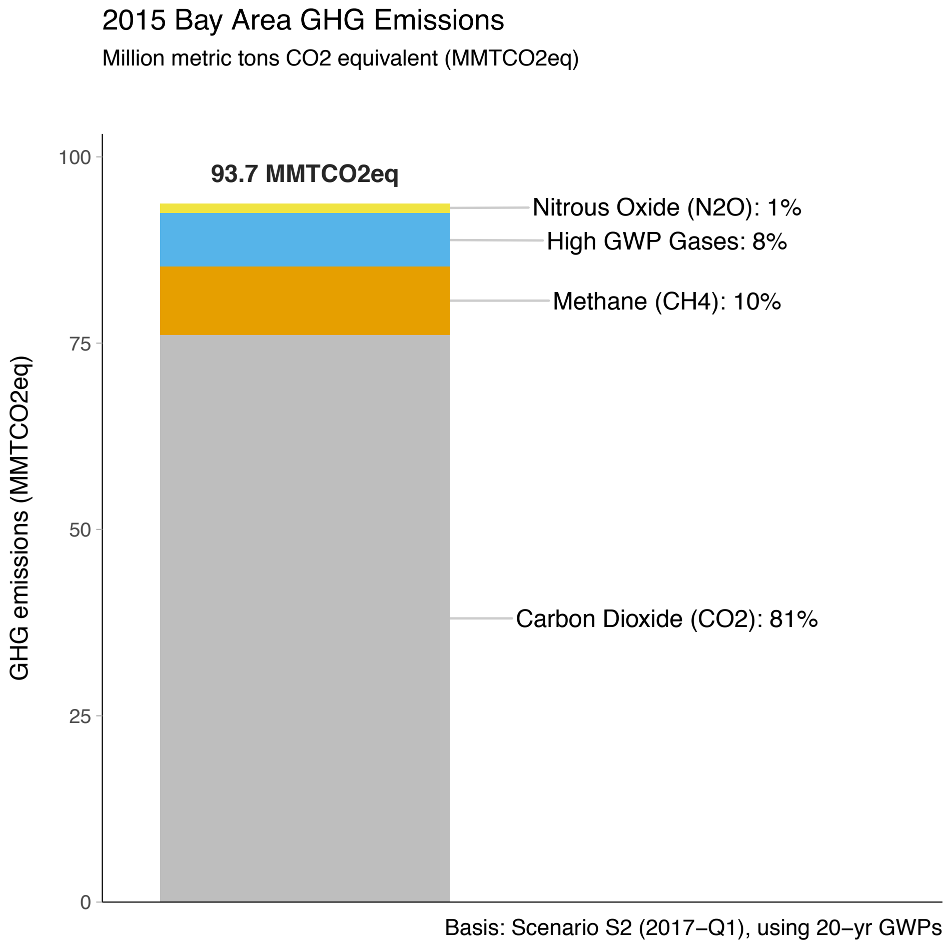

Figure 4. *Bay Area GHG emissions (CO_2 equivalents) in 2015, by pollutant, using* ***20-year GWPs*** *(with carbon-climate feedbacks). The largest share of the total (94 million metric tons) still belongs to CO_2 (81%). Compared to* ***Figure 3****, a larger relative share is attributed to methane (10%) and high GWP gases (8%); a smaller share belongs to nitrous oxide (1%).*

However, 20-year GWPs can be preferable to 100-year GWPs for some purposes, such as assessing the impact of near-term reduction strategies focused on methane and other short-lived climate pollutants. Using 20-year GWPs, Bay Area GHG emissions total about 94 million metric tons in 2015. Most of the total (81%) is still contributed by CO_2 (Figure 4), with methane contributing 10% and high GWP gases contributing 8%. The contribution of nitrous oxide, a potent but relatively long-lived pollutant, is 1%. Compared to the estimates based on 100-year GWPs (Figure 3), a larger fraction of the total impact is attributable to methane. This is because of its relatively short half-life, compared to other major GHGs.

GHG Emission Estimates by Sector

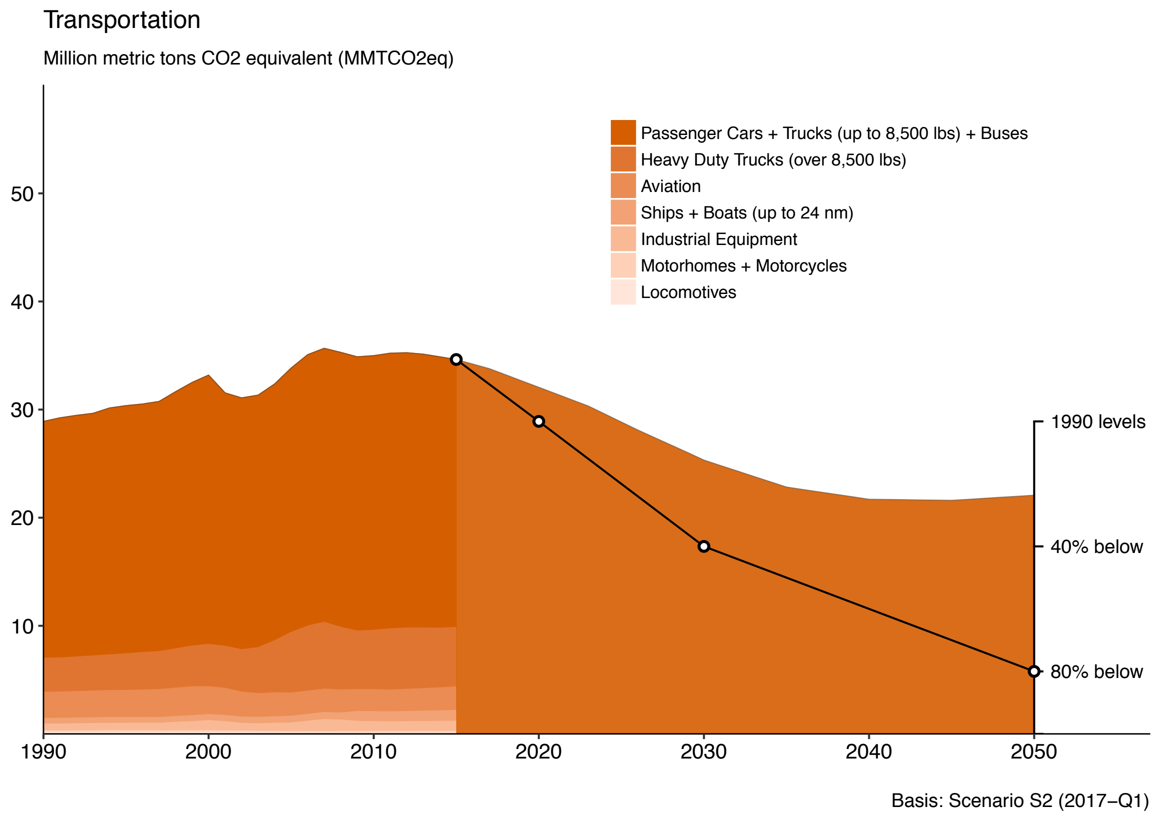

Figure 5. Projected GHG emissions for the Transportation sector, reported in million metric tons CO_2 equivalent (100-year GWPs, left axis) and relative to 1990 (right axis). Under aggressive regulations that reduce on-road motor vehicle emissions, including Advanced Clean Car Technologies, Low Carbon Fuel Standards, and Heavy-Duty Vehicle Efficiency Standards, GHGs from on-road motor vehicles are projected to decline between 2015 and 2040, and level off between 2040–2050. Steady growth in off-road mobile source activity — including shipping, aviation, and industrial/construction equipment — is projected to overtake anticipated reductions from committed and likely policies before 2050.

The emissions attributed to the Transportation sector (Figure 5, Figure 6) are direct, tailpipe emissions. Leakage of refrigerants from mobile sources is accounted for in the High GWP Gases sector. Emission forecasts mirror regional projections embedded in the State Implementation Plan (SIP) scenario from ARB's VISION2.1 model (ARB 2017b), which includes an adaptation of ARB's latest emissions model for on-road vehicles, EMFAC2014.

For on-road vehicles, ARB's VISION2.1 model includes the effects of relevant State policies and programs (SB375, Cap and Trade, Pavley, RPS, LCFS, ZEV) that, as of early 2017, are projected to enable the State to achieve its SIP targets. Pavley requirements for increased fuel Efficiency for Gasoline Vehicles are projected to result in an average 2.9% annual reduction between 2025–2030. In addition, Super Low Emission Vehicle (SULEV) sales for gasoline Light Duty Autos (LDAs) are projected to reach 100% by 2030.

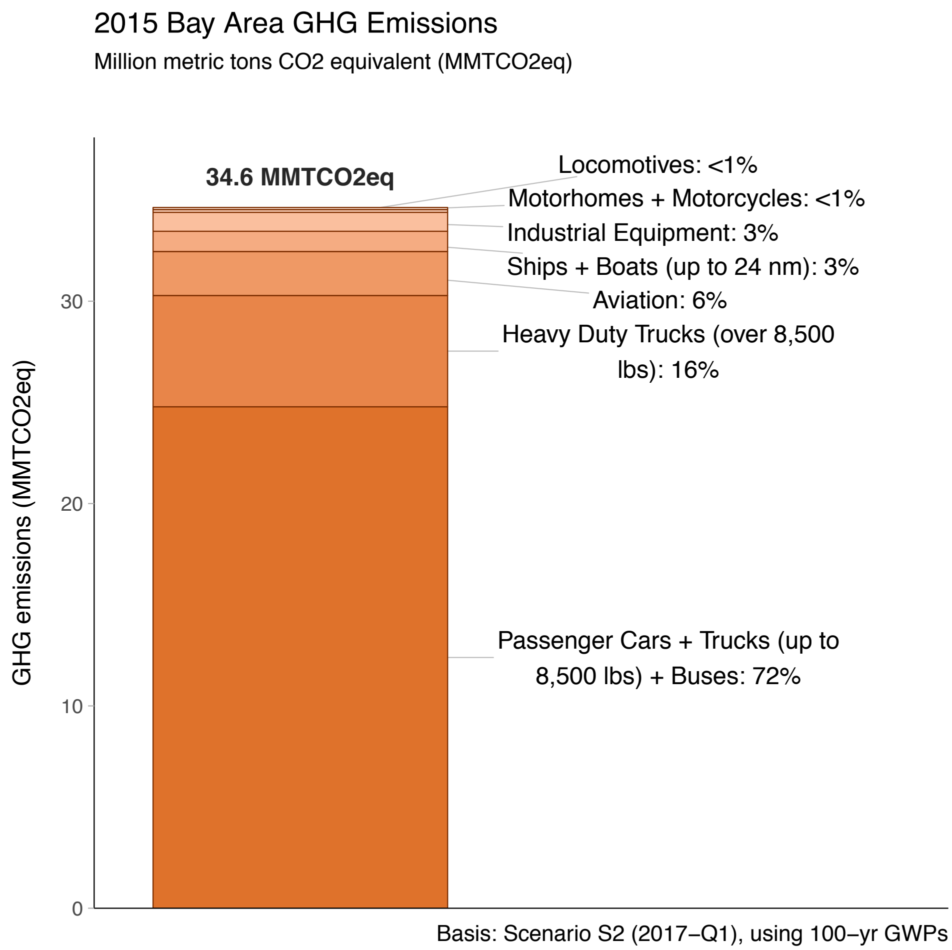

Figure 6. Bay Area GHG emissions (CO_2 equivalents) for the Transportation sector ≈ 35 $MMTCO_2eq$ in 2015. In the Bay Area, this sector contributes about two-fifths of the 2015 total (this is also true for California as a whole). Passenger cars and light/medium-duty trucks produce the majority of Transportation emissions (72%); heavy-duty trucks contribute the second-largest share (16%); the remainder (12%) is produced by off-road mobile sources, including ships, boats, aircraft, industrial/construction equipment, and locomotives.

Zero-emission vehicle (ZEV) rules and sales projections are also taken into account. Between 2025–2030, LDA, LDT and Plug-in EV sales are projected to increase from 18% to 40%, and between 2026–2030, Medium Duty and Plug-in EV sales are projected to increase from 0% to 10%. Projected ZEV bus sales begin in 2018 and increase to 100% by 2030.

Forecasts for off-road vehicles are modeled using the BA-CALGAPS model. Projections using BA-CALGAPS include a 75% increase in rail energy use (as electricity) by 2020, with simultaneous 18% decrease in aviation energy, due to high-speed rail. Additionally, Shore Power for Ocean-Going Vessels results in an 18% decrease in electricity use in 2020 in the Ships and Boats subsector.

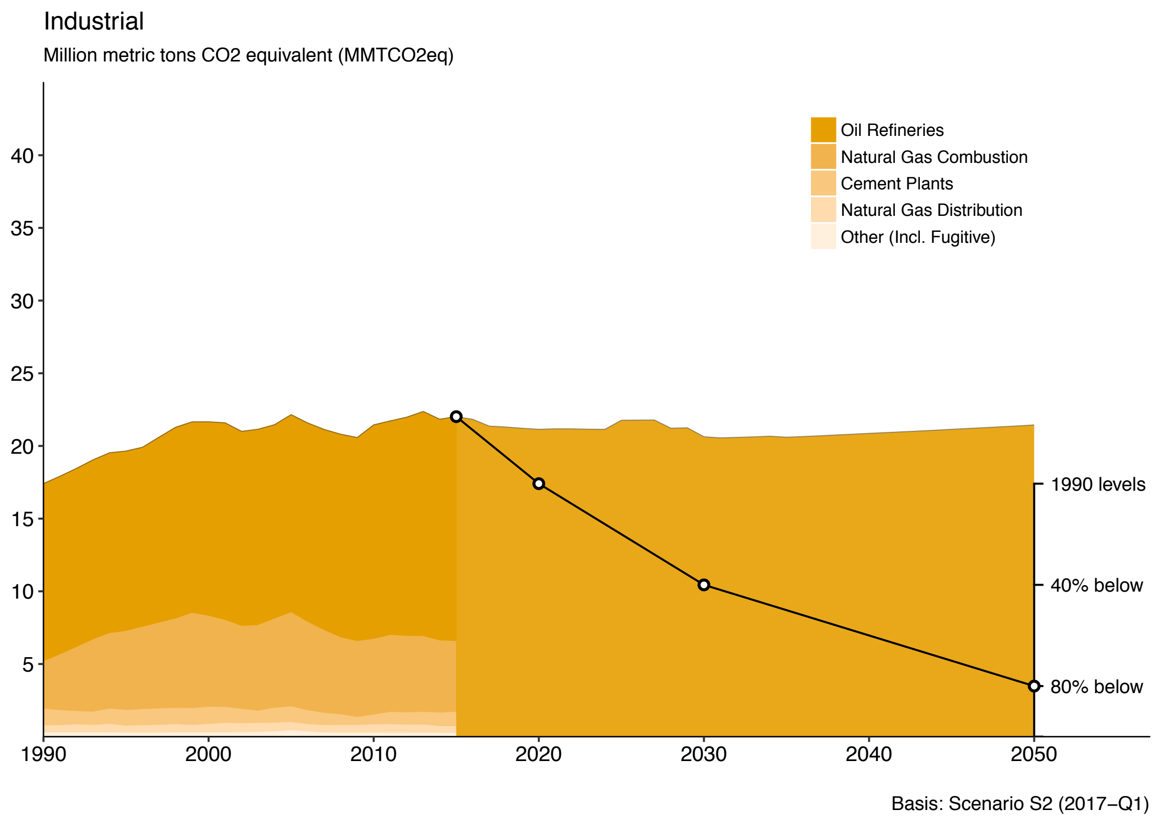

Figure 7. Bay Area GHG emissions for the Industrial sector, reported in million metric tons CO_2 equivalent (left axis) and relative to 1990 (right axis). Recent trends (2010–2015) in GHG emissions from major industrial sources in the Bay Area, including petroleum refining and cement manufacturing, are based on facility-level subtotals reported via ARB's Greenhouse Gas Reporting Program (GHGRP). Future emissions (2015–2050) are projected to remain relatively steady, consistent with forecasts from the California Air Resources Board's PATHWAYS model. This projection is also consistent with past trends, current California carbon price signals, implemented and proposed practices to minimize leakage of businesses[10], and California's ability to meet its statewide 2030 goal under Cap-and-Trade.

The basis of our Industrial-sector projections is ARB's economy-wide PATHWAYS model. (Note: Fuel and travel (VMT) demand trends from ARB's VISION2.1 model are consistent with the PATHWAYS model). The PATHWAYS model, while forecasting reductions in California fuel demand, forecasts steady rates of statewide fuel production, including petroleum refining, from 2015–2050[9].

[9] In effect, this represents a decoupling of California fuel production from regional demand. Note that emissions from fuel exported out of the Bay Area were not inventoried, consistent with AB 32 and the State Scoping Plan.

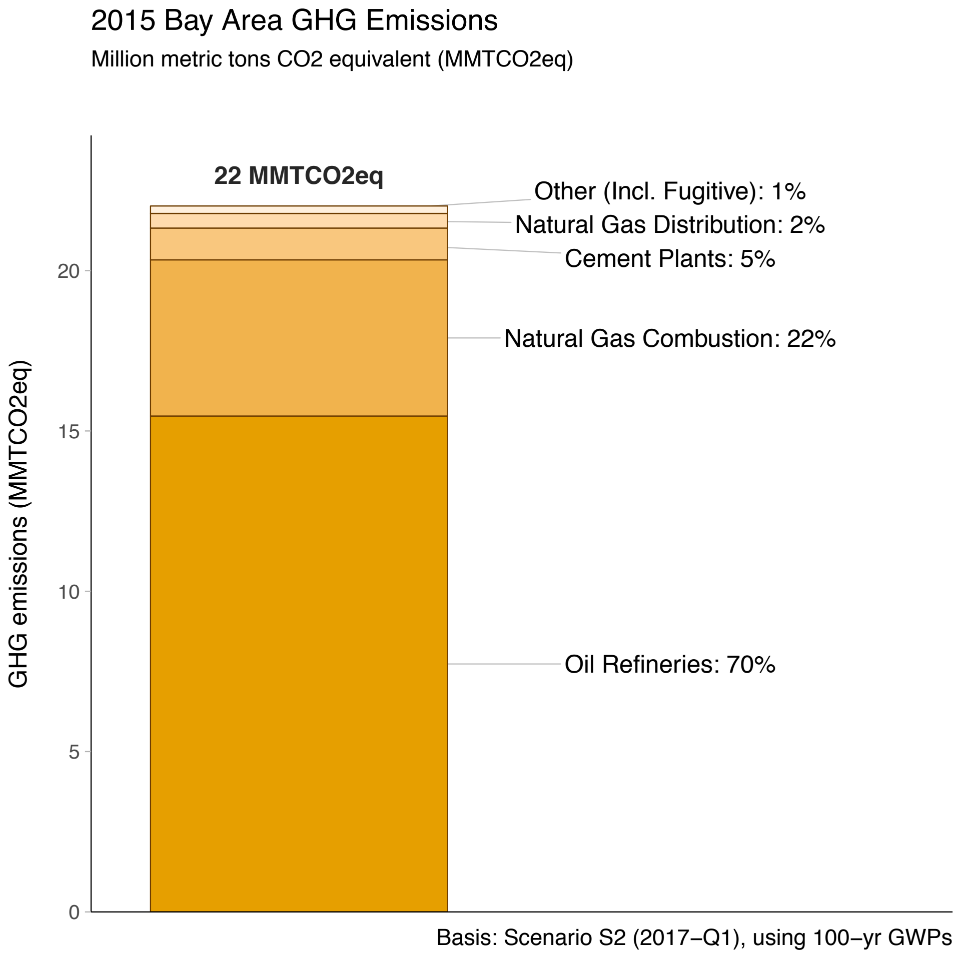

Figure 8. Bay Area GHG emissions for the Industrial sector ≈ 22 MMTCO$_2$eq in 2015. In the Bay Area, this sector contributes about one-fourth of the 2015 total. (Note: about 2 MMTCO$_2$eq from cogeneration plants located at refineries is tabulated under the "Electricity and Cogeneration" sector.) Within this sector, 70% of GHG emissions are from oil refining facilities, and 27% from other industrial facilities. The remaining 3% is composed of fugitive emissions, including fugitive methane from natural gas distribution.

The Industrial sector projections reported here (Figure 7 and Figure 8) are consistent with information available as of early 2017, including (a) current California carbon price signals; (b) implemented and proposed practices to minimize leakage of businesses and industries out of California[10]; and (c) trends in 2010–2015 GHG emissions[11] reported via ARB's GHGRP program.

[10] In particular, the relevant 2013–2015 and 2015–2018 Cap and Trade "assistance factors" (AFs).

[11] Refinery GHG emissions estimated by the District and as reported to and published by ARB have remained at a fairly constant level since 2010.

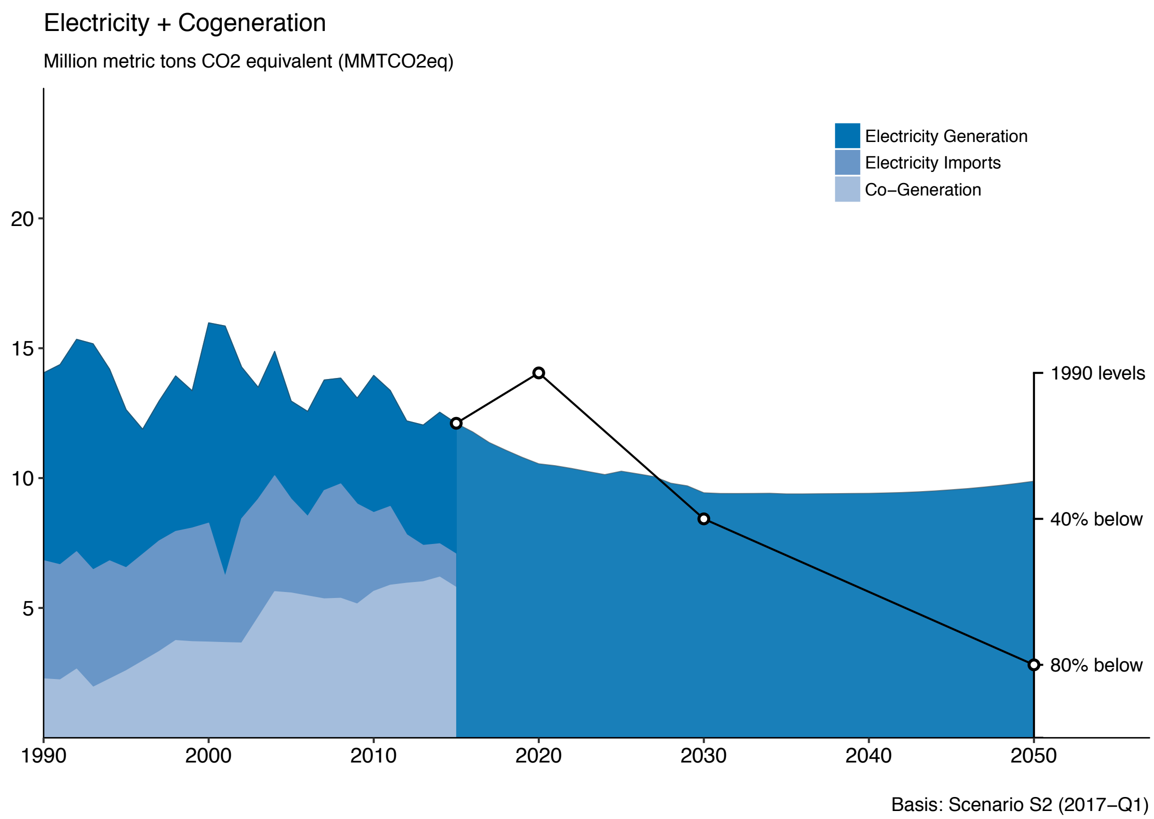

Figure 9. Bay Area GHG emission estimates for the Energy and Cogeneration sector, reported in million metric tons CO_2 equivalent (left axis) and relative to 1990 (right axis). GHG emissions from this sector are currently below 1990 levels, and are projected to decline at least until 2030. This is in large part due to California's movement toward more efficient and renewable sources, driven by requirements such as the Renewable Portfolio Standard (RPS).

Consistent with ARB's approach, electricity generation (including cogeneration) is accounted for within its own sector, and emissions attributable to electricity imported from neighboring regions (outside the Bay Area) are also included. Forecasts for the Electricity and Cogeneration sector (2015–2050) (Figure 9 and Figure 10) are based on output from the BA-CALGAPS model (Greenblatt 2013). An RPS realization of 33% by 2020 is assumed, and is complemented by about 5% of additional savings due to local programs.

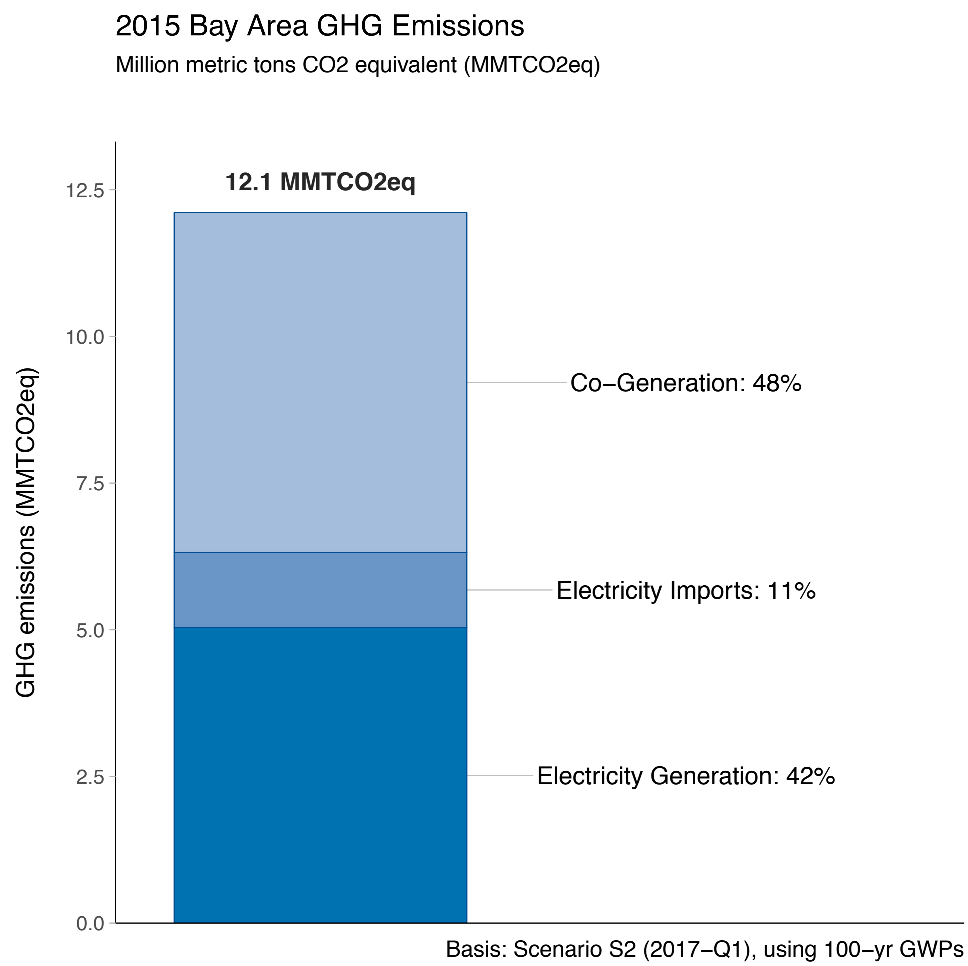

Figure 10. Bay Area GHG emissions for the Electricity and Cogeneration sector ≈ 12 MMTCO$_2$eq in 2015. In the Bay Area, this sector contributes about one-seventh of the 2015 total. Direct emissions from electricity generated at Bay Area power plants make up about half (49%) of this sector's 2015 total. Cogeneration, including cogeneration processes at industrial facilities (see note, Figure 8), contributes another 42%. The remainder (11%) is accounted for by electricity generated outside the Bay Area but imported into the region.

In addition to the RPS program, the projection also assumes 12 gigawatts (GW) statewide of Distributed Generation Photovoltaic (DG PV) beyond the California Energy Commission (CEC) 2022 PV target and an increase in Combined Heat and Power (CHP) generation and Combined Cycle Natural Gas Power Generation in line with the State Scoping Plan and the Governor's CHP goals. Forecasts for this sector also incorporate a projected 46% per capita water savings by 2020 for residential and commercial new construction, and improved lighting efficiency in buildings.

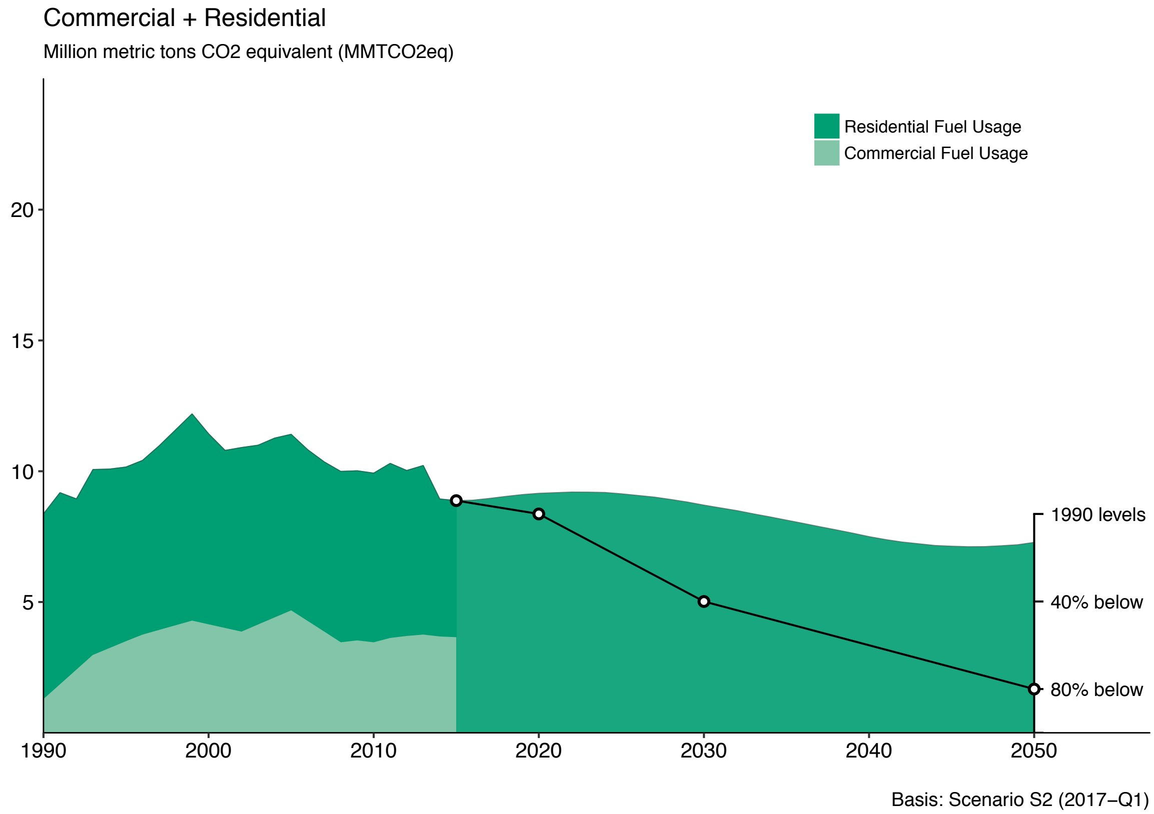

Figure 11. Bay Area GHG emissions for the Commercial and Residential sector, reported in million metric tons CO_2 equivalent (100-year GWPs, left axis) and relative to 1990 (right axis). This sector includes fuels (mostly natural gas) consumed in households and at commercial facilities. Indirect GHG emissions from residential and commercial electricity use are not included in this sector, but rather are accounted for in the Electricity and Cogeneration sector. Future reductions in GHGs, in spite of population and economic growth, are projected to come primarily from increased efficiencies and renewable energy use in new and retrofitted buildings. Renewable electricity, such as from distributed solar photovoltaic systems, is expected to offset natural gas consumption under "Zero Net Energy" (ZNE) policies.

Natural gas combustion is the dominant source of current and projected emissions attributed to the Residential and Commercial sector (Figure 11 and Figure 12). Projections for this sector, like the Electricity and Cogeneration sector, were based on statewide projections developed using the BA-CALGAPS model (Greenblatt 2013). Forecasts for this sector assume more efficient new and retrofit buildings, with new construction and retrofit efficiencies 10% better than baseline, with a 3% retrofit rate. Forecasts also assume a Zero Net Energy (ZNE) plan, under which both electricity and natural gas consumption in buildings is offset by distributed solar PV.

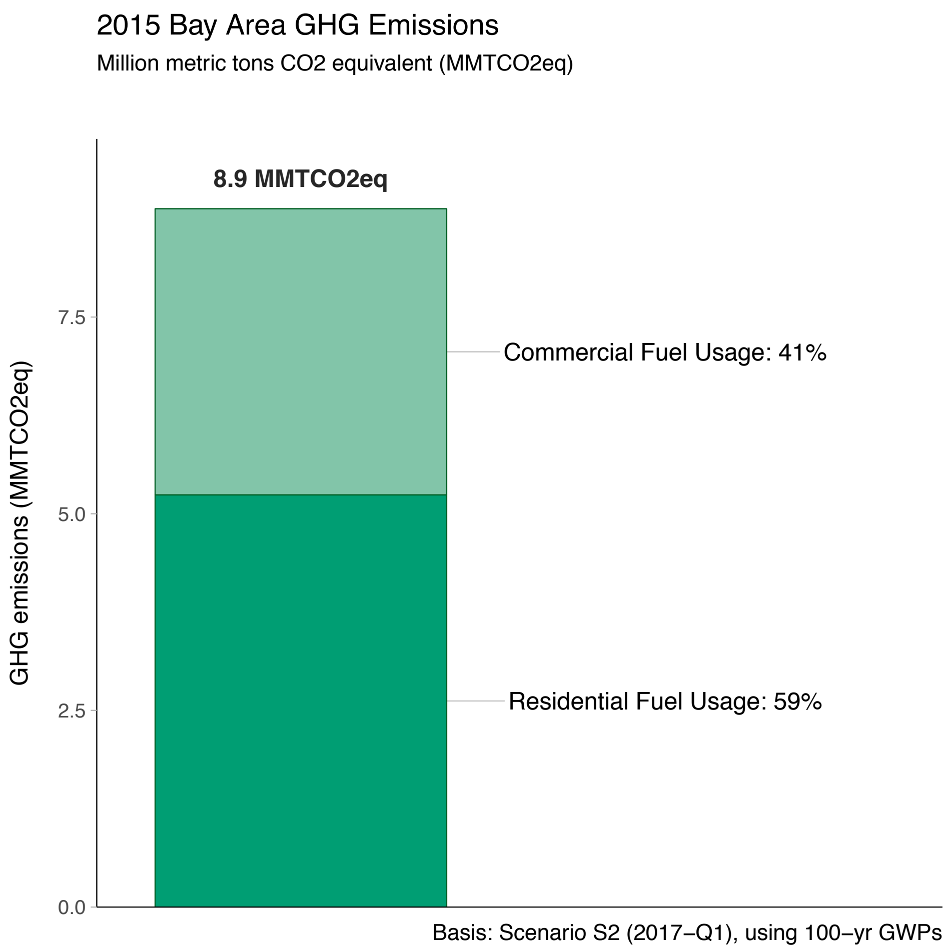

Figure 12. Bay Area GHG emission estimates for the Commercial and Residential sector ≈ 9 $MMTCO_2eq$ in 2015. In the Bay Area, this sector contributes about one-tenth of the 2015 total. Most GHG emissions (93%) from this sector are produced by the combustion of natural gas, primarily for heating and cooking. Residential space and water heating contributes 59% of this sector's total, and the remaining 41% is attributed to commercial uses. Indirect GHG emissions from commercial and residential electricity use are not included in this sector, but rather are accounted for in the Electricity and Cogeneration sector.

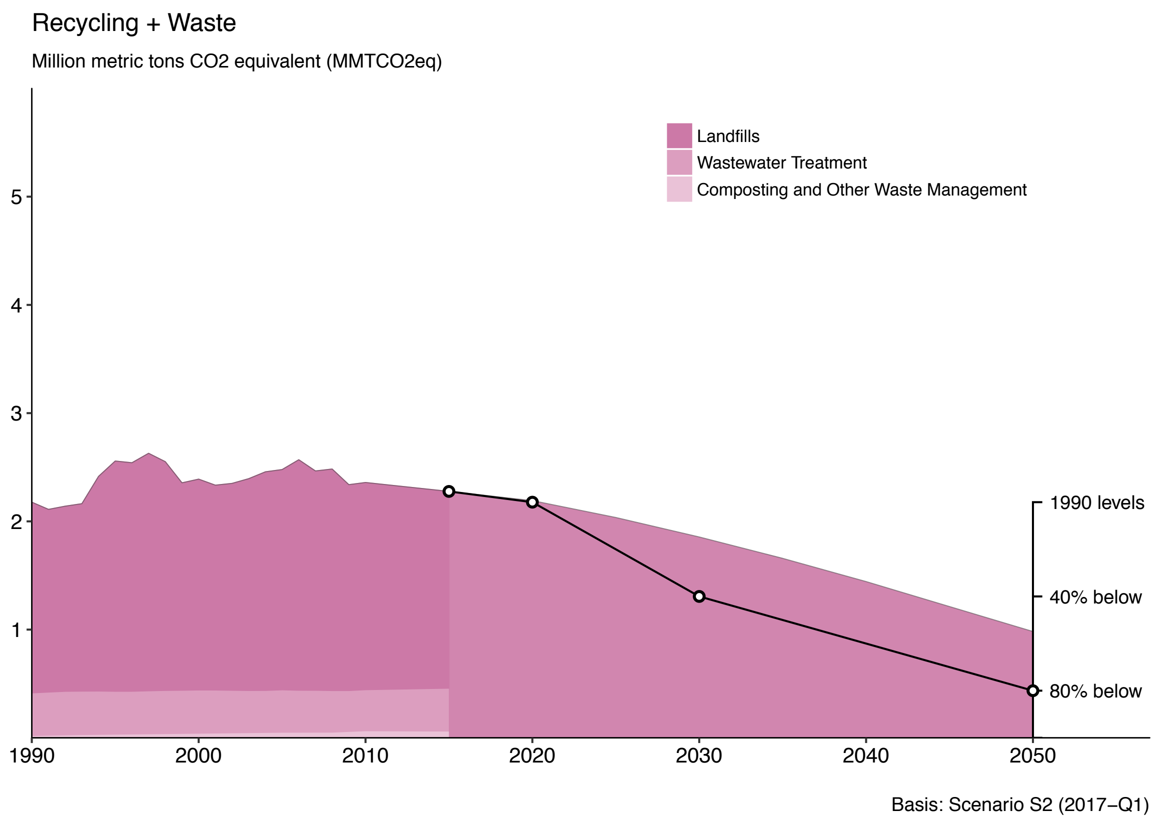

Figure 13. Bay Area GHG emission estimates for the Recycling and Waste sector reported in million metric tons CO_2 equivalent (100-year GWPs, left axis) and relative to 1990 (right axis). Under Air District Regulation 8, Rule 34, and state directives, landfill GHG emissions have not increased significantly since 1990. Reductions in future GHG emissions from this sector result from AB 341, which mandates 75% waste diversion, and from measures to capture landfill methane. (Note that landfill waste diversion does not result in immediate GHG reductions, since existing waste deposits continue to emit methane for decades.) GHG emissions from other sources in this category are projected to remain steady despite increases in the Bay Area population.

In the Recycling and Waste sector, significant state-wide GHG reduction policies include AB 341, under which 75% landfill waste is diverted by 2020, and the Zero Net Emissions policy, under which the non-biogenic component of landfills is eliminated by 2035. (Note: Consistent with Scoping Plan GHG emissions inventories, exported waste is not inventoried in this sector.)

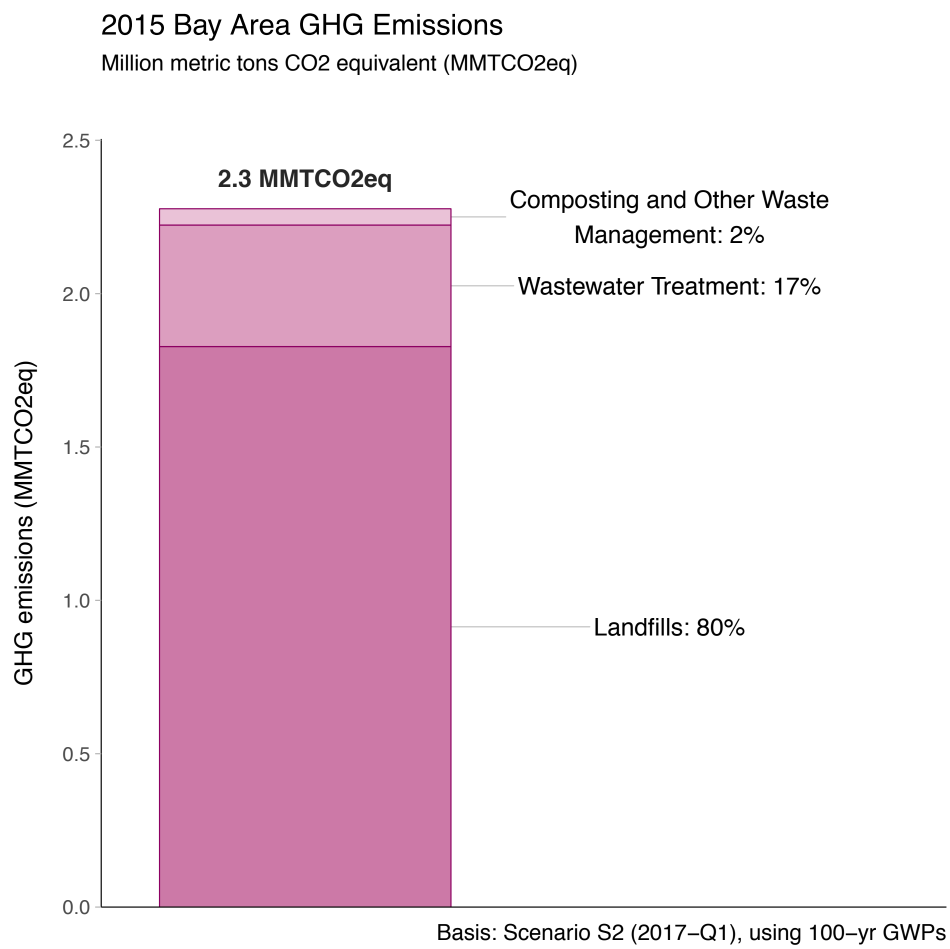

Figure 14. Bay Area GHG emissions for the Recycling and Waste sector ≈ 5 MMTCO$_2$eq in 2015. In the Bay Area, this sector accounts for 3% of the 2015 total, mostly (92%) in the form of methane emissions. (Note: these estimates are based on the use of 100-year global warming potentials.) Within this sector, the majority of GHG emissions (85%) are generated by landfills. Wastewater treatment contributes another 14%, and the remaining 1% is attributable to composting and other waste management. Note that this sector does not account for exported waste that is generated within the Bay Area.

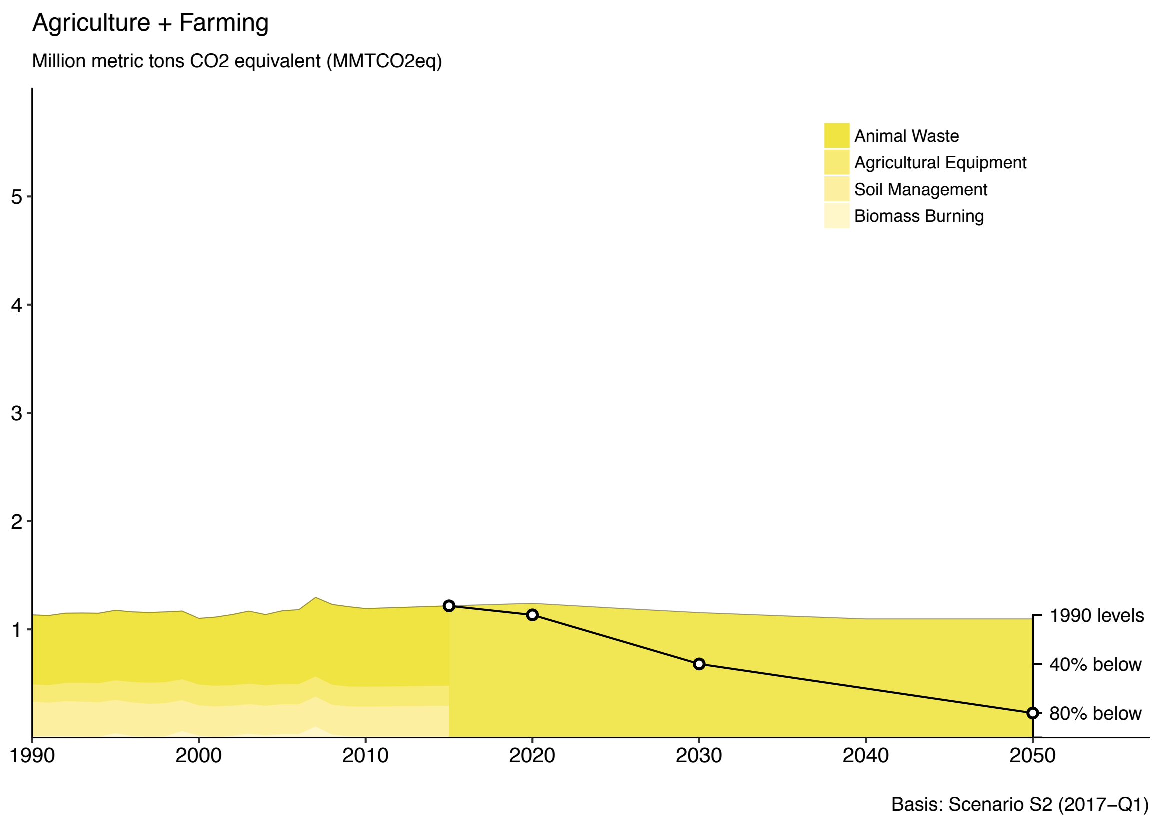

Figure 15. Bay Area GHG emission estimates for the Agriculture and Farming sector reported in million metric tons CO_2 equivalent (100-year GWPs, left axis) and relative to 1990 (right axis). GHG emissions from the Agriculture and Farming sector are projected to follow a decrease in agricultural & natural resources-related employment between 2015 and 2050. Regional and local policies, such as digesters to capture methane emissions from livestock manure, are assumed to produce only modest reductions in GHG emissions.

Labor and population projections published by the Association of Bay Area Governments (ABAG) form the basis of projections for the Agriculture and Farming sector (Figure 13 and Figure 14) and the Recycling and Waste sector (Figure 15 and Figure 16), respectively. Because of the relatively small sizes of Bay Area animal-waste operations, only minor GHG emission reductions are expected in the Agriculture and Farming sector.

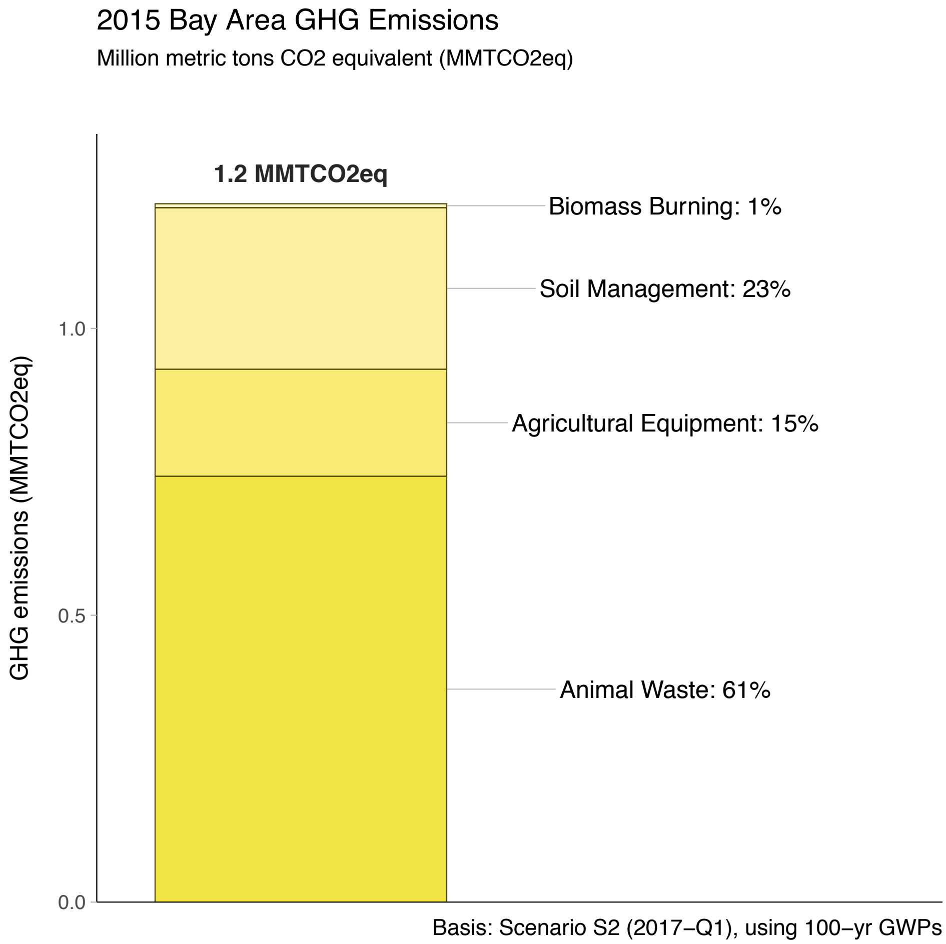

Figure 16. Bay Area GHG emission estimates for the Agriculture and Farming sector ≈ 1 $MMTCO_2eq$ in 2015. In the Bay Area, this sector accounts for 1% of the 2015 total. (Note: these estimates are based on the use of 100-year global warming potentials.) Within this sector, the majority (61%) of GHG emissions are contributed by methane emitted from animal waste. Other sectors include soil management (23%); agricultural equipment (15%), such as tractors, portable generators, and irrigation pumps; and biomass burning (less than 1%).

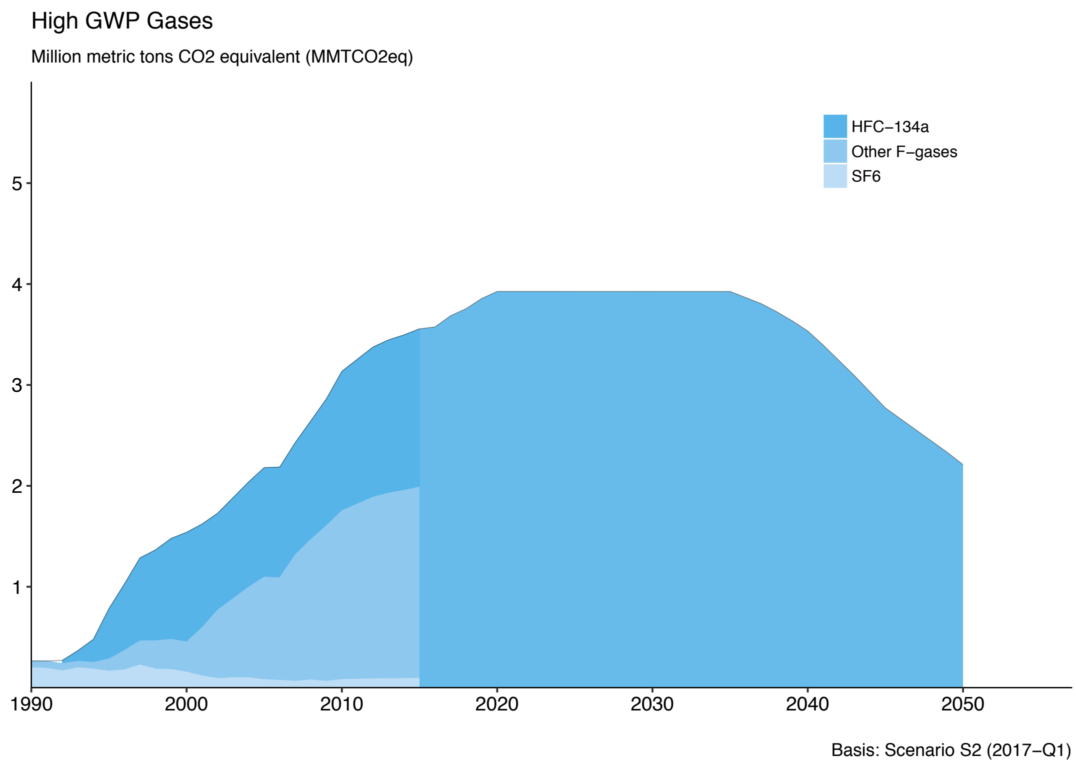

Figure 17. Bay Area GHG emissions for the High Global Warming Potential (GWP) Gases sector, reported in million metric tons CO_2 equivalent (left axis) and relative to 1990 (right axis). Since 1990, ozone-depleting substances (CFCs and HCFCs; not shown) have been aggressively phased out under the 1987 Montreal Protocol. In turn, their substitutes, including HFCs and some other fluorinated gases (F-gases), have come to constitute the majority of GHG emissions accounted for by this sector. These projections are based on a projected HFC phase-out, conformant to the Kigali Amendment to the Montreal Protocol: 50% of HFC supply eliminated by 2035; 100% by 2050. (Note: as with landfilled organic waste, there is generally a significant lag between modeled supply reductions and modeled emission reductions in this sector. These projections are based on an estimated average 15-year lag.)

PFCs, HFCs, and SF_6 are the main GHG emissions contributing to the High GWP Gases sector (Figure 17 and Figure 18). (Note: Methane and nitrous oxide are included in other sectors.) Forecasts for this sector were based on projections from the BA-CALGAPS model (Greenblatt 2013) that include existing regulations for high GWP gases, an assumed 5% reduction in HFC usage by 2020, a 50% reduction by 2035, and near complete elimination by 2050.

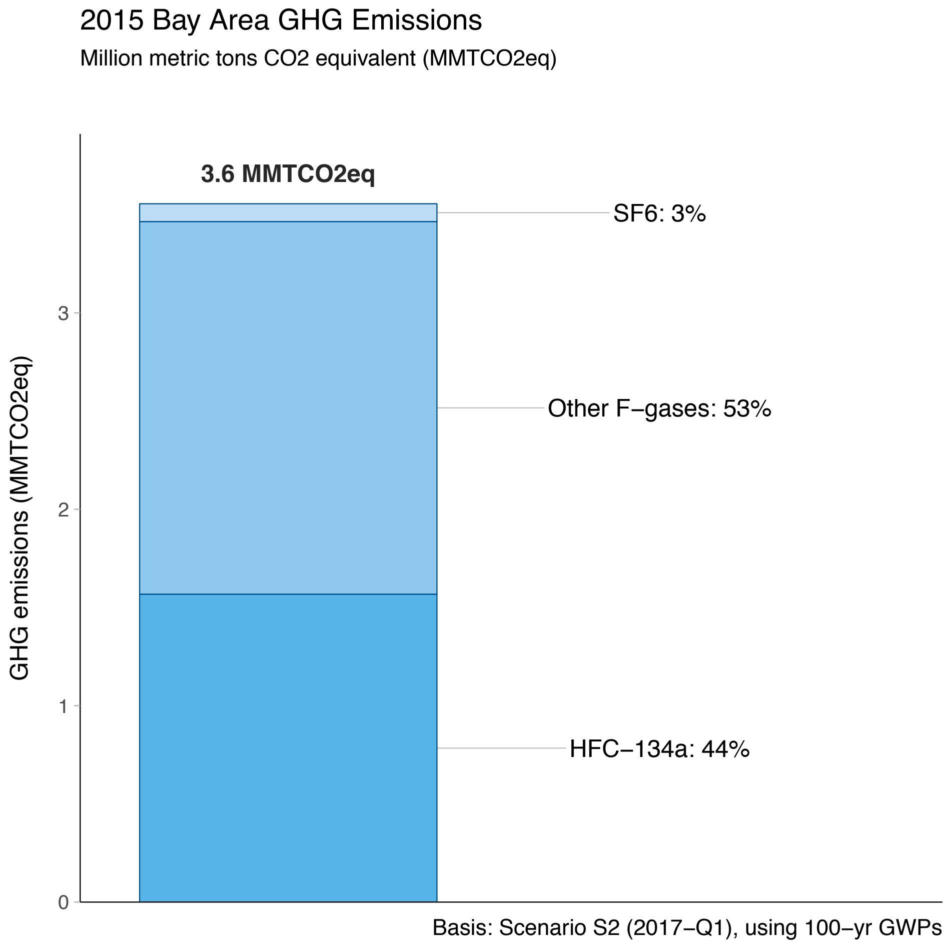

Figure 18. Bay Area GHG emissions for the High Global Warming Potential (GWP) Gases sector ≈ 4 $MMTCO_2eq$ in 2015. The High GWP Gases sector accounts for 4% of the total Bay Area GHG emissions in 2015. Within this sector, a single high GWP gas (HFC-134a) accounts for an estimated 44%. Other F-gases (such as HFC-125, HFC-143a, HFC-32, HFC-236fa, CF_4, and NF_3), which are compounds used as ozone-depleting substance substitutes or used in the semiconductor industry, account for another 53% of this sector. Sulfur hexafluoride (SF_6), used in the semiconductor and power distribution industries, contributes 3%.

Discussion of Results

A major finding of this Bay Area GHG emissions forecast results is that, with committed and expected policies in place, the Bay Area is not likely to meet the goal of reducing regional GHGs to 1990 levels by 2020. Specifically, Figure 1 shows that Bay Area GHG emissions totaled about 72 $MMTCO_2eq$ in 1990, whereas current projections indicate that the total will be about 80 $MMTCO_2eq$ in 2020.

In contrast, State projections suggest that California, as a whole, is on track to meet its 2020 GHG goal. However, the Bay Area projection is consistent with the State projection. To understand this, there are three important points to consider:

- First, because of the Bay Area's relatively strong economic growth since 1990, compared to the State as a whole[12], GHG emissions in the Bay area have also grown more. Reverting to 1990 levels, therefore, requires a larger relative reduction.
- Second, the Bay Area represents about one-fifth of the State's GHG emissions. If it is more feasible to reduce GHG emissions in other parts of the State, then it is possible, and perhaps even likely, that the State-wide target will be met mostly by cutting emissions from sources and/or sectors that are disproportionally represented in other regions, such as the South Coast or the San Joaquin Valley.
- Third, offsets are not accounted for in these Bay Area projections. Under the State's Cap-and-Trade Compliance Offset Program, up to 8% of capped GHG emissions may be offset by purchased allowances, which can come from reductions elsewhere.

Thus, the average rate of GHG reduction needed to meet the 2020 target is greater for the Bay Area than for California. The State's 2020 goal is 431 $MMTCO_2eq$[13] and the latest estimate (2014) is 442 $MMTCO_2eq$[14]; so, to reach the 2020 goal, California as a whole must reduce its GHG emissions by about 2–3% over the next several years. Considering the Bay Area in isolation, we estimate that a 10% reduction from present-day (2015) emissions would be needed to reach 1990 levels (80 *vs.* 72 $MMTCO_2eq$, respectively).

A challenge for the Bay Area, as for California, is to demonstrate reductions in GHGs while maintaining economic growth. The Air District's Regional Clean Air and Climate Strategy, which draws from this report, addresses this challenge. Meeting the 2020 goal will be

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[12] Since 1990, the Bay Area has experienced greater job growth than other parts of the State. For example, between 1990-2014, the Bay Area increased non-farm jobs by 24%, keeping pace with the region's population growth. In contrast, over the same period, Los Angeles County increased jobs by only 1%, while population grew by 14%.* During the recession, all regions of the State lost jobs. However, in 2008-2009, Bay Area job loss was a about a 5%, compared to a 6% reduction in California.**

[13] Calculation of the original 1990 limit approved in 2007 was revised to 431 MMTCO2eq, using the IPCC 2007 fourth assessment report (AR4) global warming potentials. The Board approved this revised estimate as the 2020 emission limit with the approval of the First Update to the Scoping Plan on May 22, 2014. https://www.arb.ca.gov/cc/inventory/1990level/1990level.htm

[14] 2016 Edition of the GHG Emission Inventory Released (June 2016). https://www.arb.ca.gov/cc/inventory/data/data.htm

challenging for the Bay Area, but to meet the 2050 goal, as shown in Figure 1, will require significantly greater reductions than the policies represented in our current forecast.

Next Steps

The Caveats and Assumptions section highlighted issues that will be addressed as next steps to refine current GHG estimates and forecasts. Specific areas for future development are listed below:

- Current emission inventory estimates relied primarily on a 2011 base year, supplemented by 2010–2015 trends developed specifically for the Industrial, Electricity and Cogeneration, and Residential and Commercial sectors. Work underway will develop an integrated 2015 base year, including updates to estimates for on-road vehicles, using EMAC2014 and the Vision 2.1 model.
- A Quality Assurance Project Plan (QAPP) for the agency's emissions inventory reporting will help refine stationary-source GHG emission estimates for years prior to 2015.
- Observation-based studies to evaluate regional and source-specific methane emission estimates are currently underway at the Air District. These studies will also help refine GHG emissions reported here.
- Some sector forecasts (2015–2050) reported here were derived from statewide forecasts. Future forecasts will aim to develop forecasts for Bay Area-specific sources within the Scoping Plan sectors.
- A more fine-grained development of forecasts to individual sources within sectors will be more useful for informing the Air District's policy development and climate protection strategies.
- Future efforts will update forecasts to incorporate the most recent statewide policies (adopted after mid-2016), for example to represent recent implementations of SB 350, adopted in 2015 and evolving policies for the industrial sector. This work will also include improved representations of Bay Area regulations under development for reducing GHGs, such as efficiency improvement requirements.
- The scope of future GHG emission inventories will be broadened to include GHG sources and sinks from Natural and Working Lands, and to include other climate-forcing pollutants such as black carbon

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Appendix A: BA-CALCAPS: GHG Inventory Model for the Bay Area

Jeffery B. Greenblatt
March 21, 2017

Summary: BA-CALGAPS was based on CALGAPS to calculate historical and projected greenhouse gas (GHG) emissions for the San Francisco Bay Area (SFBA). We made use of SFBA-specific data wherever possible, complemented by scaled statewide data based on population, gross regional/state product (GRP/GSP) and other relevant metrics.

Population
Data sources:

- Statewide: California Department of Finance (DOF) 2013 projections (2010 to 2060)
- SFBA: Association of Bay Area Governments (ABAG) population projections by county (1980 to 2040)

Total SFBA population calculated using fraction of Solano and Sonoma County populations under BAAQMD jurisdiction (~70% and ~87% respectively in 2010), as estimated by BAAQMD. SFBA projections from 2041-2050 were extrapolated using average annual growth rate from 2030–2040 (0.91%).

Data on number of households was also provided and used to derive number of people per household, which changed slowly with time. This index was used to convert from population to households for use in the residential building model.

Gross regional/state product (GRP/GSP)
Data sources:

- Statewide GSP: U.S. Department of Commerce Bureau of Economic Analysis (BEA)
- SFBA GRP: ABAG projections from 1990 to 2035

SFBA projections from 2036-2050 were extrapolated using the assumed fixed growth rate from 2021-2035 (2.50%).

Commercial floor space (expressed in square feet) used to normalize commercial buildings, and manufacturing output (expressed in dollars, distinct from GRP/GSP) used to normalize a small handful of subsectors (manufacturing, mining and non-PV self-generation), were based on statewide data provided from the stationary model and were themselves normalized by GSP, in order to estimate them for the SFBA.

Light-duty vehicles

Data sources:

- EMFAC2014 (v1.0.7) for BAAQMD (2000–2050). Used EMFAC2011 categories, included all vehicles ≤8,500 lbs. gross weight (including motorcycles and medium-duty trucks). Used to provide vehicle counts, annual vehicle miles traveled (VMT), and energy efficiency (energy consumption per mile).
- Air Resources Board (ARB) for statewide data (2010–2050), using EMFAC projections from 2013. Used to provide vehicle shares by engine/fuel technology, some energy efficiency data, and CO_2 emissions intensities.

Number of vehicles scaled by SFBA population.

Note that motorcycles were included in total LDV vehicle counts; due to its small size, no separate category for motorcycles was included. Medium duty trucks (gross vehicle weight 6,000-8,500 lbs.) had erroneously been included as part of heavy-duty vehicles previously.

CALGAPS drivetrain/fuel categories modeled:

- Conventional gasoline
- Hybrid electric vehicle (HEV) gasoline
- Plug-in hybrid electric vehicle (PHEV) gasoline + electricity
- Electric vehicle (EV)
- Fuel cell (FC) hydrogen (H2)
- Flexible fuel vehicle (FFV) using 85% ethanol (E-85)
- Conventional diesel
- HEV diesel
- PHEV diesel + electricity
- Conventional natural gas (NG)

<u>Heavy-duty vehicles</u>

Data sources:

- EMFAC2014 (v1.0.7) for BAAQMD (2000–2050). Used EMFAC2011 categories, included all vehicles >8,500 lbs. gross weight. Used to provide vehicle counts, vehicle shares by engine/fuel technology (gasoline/diesel only), annual vehicle miles traveled (VMT), and some energy efficiency (energy consumption per mile) data.
- Air Resources Board (ARB) for statewide data (2010–2050), using EMFAC projections from 2013. Used to provide natural gas vehicle shares, energy efficiency data for natural gas vehicles (scaled SFBA diesel fuel efficiencies by statewide ratios of natural gas to diesel efficiencies), and CO_2 emissions intensities.

Number of vehicles scaled by SFBA GRP.

BA-CALGAPS vehicle categories (modified from CALGAPS):

- Light heavy-duty trucks (LHD, 8,501-14,000 lbs.) + medium heavy-duty trucks (Class 6)
- Heavy heavy-duty trucks (HHD, Class 7 & 8)
- Buses and motorhomes (MH)

Drivetrain/fuel categories modeled:

- Conventional gasoline
- Conventional diesel
- Conventional natural gas (NG)
- Hybrid electric vehicle (HEV) diesel
- Plug-in hybrid electric vehicle (PHEV) diesel + electricity
- Fuel cell (FC) hydrogen (H2)
- Electric vehicle (EV)

<u>Other transport</u>
Data source: BAAQMD GHG inventory projections (1990–2029)

Vehicle/fuel categories included:

- Rail (locomotives): diesel and electricity
- Aviation:
  - Commercial (using jet fuel)
  - General aviation (using aviation gasoline)
  - Military (using jet fuel)
- Marine:
  - Ships (ocean-going vessels = OGV): diesel and electricity
  - Boats (harbor craft = HC) using diesel
  - Cargo-handling equipment (CHE) using diesel
- Off-road (OR) equipment (using diesel)

GHG emissions extrapolated from 2030–2050 based on linear fits or average across time series (usually 2008-2029), depending on observed trend. Converted to energy use using estimated fuel CO_2 intensities. Normalized to energy use per dollar GRP for consistent rescaling. Includes policies for electrification of ships (in port) and rail. High-speed rail policy reduces LDV and aviation usage based on a report by the HSR Authority; see documentation in CALGAPS paper.

<u>Residential and commercial buildings</u>
Data sources:

- Statewide: 2013 IEPR preliminary forecast data (used in CALGAPS paper). Water and waste energy intensity obtained from several sources assembled by ARB.
- SFBA: 2014 IEPR historical electricity and natural gas demand data (1990–2014) for the nine BA counties (with population-weighted corrections for Solano and Sonoma counties), plus IEPR historical (1990–2014) and projected (2015–2025) detailed

electricity demands for PG&E service territory (broken down by sector). IEPR projected EV demand is removed, since BA-CALGAPS has its own EV projections.

Used ratio of nine-county to PG&E service territory total residential and commercial electricity demands to scale detailed electricity demands to SFBA. Demand data was normalized by number of households (residential) or commercial floorspace (commercial) and extrapolated based on trends from data provided. Additional policies modified demand intensity relative to these trends.

Separate residential and commercial stock-turnover models were developed to model more efficient buildings. Three categories tracked separately for electricity and natural gas: new construction, retrofits and unaffected stock. Each category has a separate efficiency intensity that evolves annually. Net added building stock (net construction) is calculated as the sum of new construction and demolition (usually much smaller than new construction).

Other IEPR categories (for electricity: manufacturing, mining, agricultural, street lighting, and transportation/communication/utilities (TCU); for NG: manufacturing, mining, agricultural, and other) did not use a stock-turnover approach but were extrapolated from historical trends, with rates tapering toward zero between 2025 and 2050. Manufacturing and mining were normalized by manufacturing output, whereas other categories were normalized by population.

Energy savings from water efficiency in the residential, commercial, industrial and agricultural sectors were directly calculated in the stationary sector model. Statewide energy intensities were used for the SFBA. Waste efficiencies in the residential and commercial sectors were included in the model, but disabled.

<u>Electricity</u>
Data sources:

- Statewide: Numerous (documented in CALGAPS)
- SFBA: CEC data on plant type, capacity (MW) and output (MWh) in nine BA counties (with additional data supplied by BAAQMD)

Gross generation was determined from gross demand (sum of all electricity demands across stationary, transportation, hydrogen production, and other sectors), plus transmission and storage losses that were calculated as (mainly constant) fractions of gross demand. This gross generation was then met using a generation mix calculated as follows.

Used SFBA data to determine 2014-era generation mix. Ratio of renewables scaled proportionally with increasing RPS target for future years. Implemented "load filling" algorithm from CALGAPS that satisfies demand first with renewables and other fixed assets (large hydro, nuclear, coal, CHP, etc.), then load-following (natural gas + storage) and finally natural gas combined cycle to fill remaining gaps. Load-following generation is a fixed percentage of demand; however, for ≥50% renewables, this percentage was manually increased from the default 3% to 5%, to account for larger load-following demands of such scenarios. Note that storage directly reduces NG simple cycle (SC) generation, e.g., if load-following capacity is 2% of gross generation and storage is 1%, NG SC is reduced to 2%.

Imported power from outside SFBA is a specified percentage of total demand which decreases with time as in-region renewable generation increases. Assumed no exported power, since SFBA is a large net importer. Rather than specifying generation mix of imported power, used a GHG intensity schedule provided by PG&E through 2020. (Currently model continues the exponential trend to 2030, then keeps emission intensity flat.)

<u>Fuels</u>

Data sources:

- Statewide life-cycle GHG emissions of fuels were provided by ARB (documented in CALGAPS)

Statewide GHG emissions data were used for the SFBA, but upstream GHG emissions were omitted, and emissions from refineries were calculated directly for the SFBA. Downstream GHG emissions from both fossil and biomass fuels were calculated explicitly (e.g., nonzero downstream emissions from biofuels). A specified fraction of biofuels consumed in the SFBA were produced from biomass grown in-region, with upstream emissions from plant growth (negative emissions) and processing (positive emissions) explicitly included in net GHG emissions from biofuels.

Fuels represented in the model:

- Gasoline
- 85% ethanol (E-85) / gasoline blend (used in very small quantities)
- Diesel
- NG
- Jet fuel
- Aviation gasoline (used in very small quantities)
- Fuel oil (not currently used)
- Coal (used in very small quantities)
- Biomass (used for electricity)

Biomass could be substituted for an arbitrary fraction of any of the above fuels in the model.

The ability to include a changing mix of biomass feedstocks (corn ethanol, cellulosic ethanol, Fischer-Tropsch gasoline, biodiesel, etc.), in order to calculate raw biomass demand, was built into CALGAPS, but these calculations are out of date for BA-CALGAPS and should not be trusted.

High global warming potential (GWP) sector

Data sources:

- ARB statewide emissions for chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs) and other fluorinated gases, broken out by sector (residential, commercial, industrial, LDV, HDV, other transport, and electricity).
- Analysis of national HFC emissions reductions under Montreal Protocol amendment from Greenblatt and Wei, Supplementary Information ("Assessment of the climate commitments and additional mitigation policies of the United States," *Nature Climate Change,* 26 September 2016. DOI: 10.1038/nclimate3125), including projected baseline emissions from U.S. EPA ("Climate Benefits of the SNAP Program Status Change Rule," Stratospheric Protection Division Office of Atmospheric Programs Office of Air and Radiation, EPA-HQ-OAR-2014-0198-0239, July 2015. http://www3.epa.gov/ozone/downloads/SAN_5750_SNAP_Status_Change_Rule_NPRM_signature_version-signed_7-9-2014.pdf).

Statewide data were normalized by population (residential, electricity), GSP (commercial, industrial, other transport), or number of vehicles (LDV, HDV). SFBA emissions were obtained by scaling with local data. Note that CFCs and HCFCs were not included in the inventory because these gases are already controlled by international treaty and are being phased out.

The Proposed Montreal Protocol Amendment required the U.S. to reduce HFC consumption to 90% of baseline by 2019, 65% by 2025, 30% by 2030 and 15% by 2036. Greenblatt and Wei developed an inventory model based on this data (along with projected EPA emissions in the absence of HFC regulations) to estimate HFC emissions under this policy through 2030. The Montreal Protocol Amendment that was adopted in late 2016 was slightly less stringent than what was proposed; Wei (pers. commun., 2016) estimated it would achieve ~80% of the calculated reductions. The adjusted emissions reductions used in BA-CALGAPS were 10% 2020, 27% in 2025 and 50% in 2030.

"Other" sector (industrial, agricultural and forestry)

Data sources:

- BAAQMD GHG inventory projections (1990–2029)
- ARB statewide inventory (1990–2011)

Extrapolated trends from GHG emissions, normalized by population or GRP as appropriate for ease of rescaling.

Categories based on SFBA data:

- Cement
- Landfills
- Manure management
- Agriculture (soils and energy use)

Categories based on statewide data:

- Oil & gas activities (extraction, pipelines, refining, not specified)
- Methane leakage
- Wastewater treatment
- Enteric fermentation
- Other agricultural
- Net CO_2 flux from forests

Agricultural offsets due to in-state biomass fuel production were calculated from fuel demand.

<u>Scenarios</u>

S1* and S2* scenarios developed specifically for the SFBA. S1* represents an updated set of currently committed policies for the state and SFBA, whereas S2* adds additional potential policies on top of S1*. Model includes capacity for two other scenarios (currently labeled S3 and S0), but these were not updated for the SFBA. List of all policies included in scenarios S1* and S2* provided on following pages, along with statewide (CALGAPS) S1 and S2 scenarios for comparison.

Recent enacted and potential policies not explicitly included:

- LCFS enhancement: reduce fuel carbon intensity 18% in 2030 (unclear how will be accomplished; S2 comes close to this already)
- Mobile source strategy:
  - 4.2 M ZEVs by 2030 (unclear mechanism; S1* reaches ~2.1 M statewide in 2030, and S2* only reaches ~3.1 M statewide)
  - New buses 100% ZEV by 2030 (very small portion)
- SB 375: increase 2035 targets (unknown)
- Sustainable freight action plan:
  - Improve freight efficiency 25% by 2030 (would be slight improvement over federal target in S1* = 25% in 2035 – about 17.5% in 2030; S2* adds 9.5% VMT reduction in 2020 which meets this goal)
  - Deploy 100,000 ZEVs by 2030 (cumulative not annual rate; thus is a small fraction of total fleet)
- SB 1383:
  - Reduce HFCs 40% by 2030 (S2* exceeds this anyway)
  - Reduce CH4 40% by 2030 (unclear how this will be accomplished. S2* landfill emission already reduced to 100% in 2035.)
- Refinery sector: Reduce GHG emissions 20% (unclear mechanism)
- AB 1504 and SB 1386: Increase natural and working lands CO2 sink (quantitative targets not given; Bay Area has no significant land sinks)

Table of policies included in CALGAPS and BA-CALGAPS, by scenario:

		CALGAPS		BA-CALGAPS		
		S1	**S2**	**S1***	**S2***	**Notes**
Vehicles						
ZEV		1.5M (6%) in 2025, 13% in 2050	Same as S1	Same as S1	Follows S3 scenario (60% ZEVs in 2050)	Have included a more aggressive ZEVs policy assuming vehicles will be pursued
VMT reduction		No change from baseline (SB375)	Same as S1	Same as S1	Same as S1	
LDV ICE efficiency		Pavley 1&2 (double average ICE fuel efficiency by ~2040)	Same as S1	Same as S1 with BA vehicle efficiencies (slight change)	S1 with automation (25% savings by 2050)	Automation more likely now
HDV efficiency		No VMT, efficiency change from baseline; NG share 1% in 2030	9.5% VMT reduction below baseline, 1.3% efficiency boost in 2020;	Same as S1 but with federal HDV policy efficiency improvement (10% in 2025, 25% in 2035, 33% in 2050)	Same as S1* with 9.5% VMT reduction in 2020	Small efficiency boost in S2 overwhelmed by federal policy, so ignore
Other transport		18% marine electrification in 2020	Same as S1 with high speed rail	Same as S1 with 30% rail electrification in 2030 (provided by Tan Dinh)	Same as S1* with high speed rail @ 30% of statewide ridership	S2*: estimated share of HSR energy use taking place in BA
Fuels						
Biofuels in-state portion		12% gasoline, 100% diesel & jet fuel	2020: 24% gasoline, 100% diesel & jet fuel. All ramping by 2050 to 75%	Same as S1	Same as S2	
Low carbon fuel standard		Gasoline: 22% biofuels in 2020 (decrease in GHG intensity is ~10%); diesel: 5%; NG, jet fuel: 0%	Gasoline & diesel ramp to 31% biofuels in 2030; NG, jet fuel unchanged	Same as S1	Same as S2	

Hydrogen		No policy	Same as S1	Same as S1	Same as S1	Ability to model H2 demand across sectors exists, but none included
Buildings						
Building efficiency		0.3%/yr retrofit rate (residential & commercial), moderate efficiency gains for all building types	3%/yr residential retrofit rate by 2020, aggressive efficiency gains for new and retrofit residential, and new commercial	2.9%/yr retrofit rate (residential & commercial), 20% efficiency gain by 2030, 50% by 2030 for all buildings	Same as S2 with slightly lower retrofit rates	SB350 requires aggressive efficiency gains in all buildings (retrofit rate tapers to 0%/yr btw 2040–2050)
Building electrification		None	Same as S1	Same as S1	Residential and commercial new construction: 25% in 2020, 60% in 2030, 100% in 2050; slightly lower for retrofits)	S2* is the S3 scenario, as think electrification now more likely
ZNE targets		None	New construction: 100% ZNE residential buildings by 2020 and commercial by 2030. Retrofits: No residential goals; 50% commercial buildings by 2030 (100% by 2050).	Same as S1	Same as S2	
Other stationary efficiency		No change from forecast rates through 2025; savings taper toward 2045	Same as S1	Same as S1	Same as S1	
Water savings efficiency		20% savings by 2020 (residential and commercial)	46% savings by 2020 (residential and commercial), derived from an additional 3.9 MtCO2e savings	Same as S1	Same as S2	

Electricity						
RPS target		33% in 2020, fixed thereafter	4% higher than S1 due to local actions	50% in 2030 (SB 350), then fixed	4% higher than S1* due to local actions	No changes due to Clean Power Plan; local actions likely will continue to exceed state target
Renewable generation mix		Based on statewide 2013 forecasts (mix of wind, biomass, geothermal, solar, small hydro); fixed after 2020	Same as S1	Based on 2014 Bay Area generation mix (mainly wind with some solar and biomass); fixed in subsequent years		
Distributed PV not part of RPS		2,200 GWh/yr by 2022 statewide; fixed therafter	25,000 GWh/yr by 2020 statewide; fixed thereafter	0.5% in 2020 (440 GWh/yr); % grows with RPS target	10% in 2020 (5000 GWh/yr); % grows with RPS	Approximately 20% of statewide levels
Nuclear		No (phase-out by 2024)	Yes	Same as S1	Same as S1	New nuclear very unlikely
CCS		No	300 MW statewide in 2020, flat after	Same as S1	0.8% (60 MW) of generation by 2030, flat after	Scaled by Bay Area population
Large hydro		Fixed at long-term average statewide (33,000 GWh/yr)	Same as S1	None	Same as S1*	No large hydro in Bay Area
CHP		Fixed at 8.5 GW statewide	Increase to 15 GW by 2030	Fixed at 18% of generation	Same as S1*	CHP increase unlikely in Bay Area as GHG benefit is weak
Imports into region		24% in 2010, 10% in 2025+	24% in 2010, 0% in 2025+	34% in 2014, 14% by 2030, then flat	34% in 2014, 10% by 2030, then flat	Reflects recent Bay Area imports
Exports from region		5,100 GWh/yr statewide through 2020, then taper to 50% by 2030	Same as S1	None	Same as S1*	Bay Area is net importer

Imported electricity GHG intensity		N/A	N/A	Follow PG&E target through 2020, trend line to 2030 (71% of 2020 value), then fixed	Same as S1*	Bay Area imports are handled differently than in statewide model
Imported coal phase-out		Yes	Same as S1	None	Same as S1*	No coal in Bay Area
Once-through cooling phase-out		Yes	Same as S1	None	Same as S1*	No once-through cooling in Bay Area
Energy storage		None	0.4% in 2020 statewide (1.3 GW @ 10% capacity factor)	Same as S1	Same as S1	Storage is small statewide; ignored for Bay Area
Total load-following		3% of generation in 2020, then fixed	Same as S1	3% of generation in 2020, 5% in 2030, then fixed	Same as S1*	Increase after 2020 due to increased renewables; portion not supplied by energy storage is natural gas simple cycle
Other sectors						
HFC phase-out		None	2.5% in 2020, 25% in 2030, 50% in 2040, 100% in 2050	10% in 2020, 50% in 2030, 75% in 2040, 100% in 2050	Same as S1*	S1* reflects new EPA SNAP + Montreal Protocol Amendment rules
Landfill biogenic content		50% in 2010, ramp to 60% in 2020, then flat	75% in 2020, 100% in 2035	Same as S1	Same as S2	
Land sink		5 MtCO2e statewide in 2020	Same as S1	None	Same as S1*	No net sink in Bay Area
Offsets		None	8.2 MtCO2e/yr statewide in 2020, then fixed	Same as S1	1.5 MtCO2e/yr in 2020, then fixed	S2/S2* reflect local actions; Bay Area is population-scaled

Appendix B: Global Warming Potentials: Which Values to Use?

BAY AREA AIR QUALITY MANAGEMENT DISTRICT
DRAFT OFFICE MEMORANDUM

July 22, 2015

To: Henry Hilken, Abby Young, Greg Nudd

CC: Sukarn Clair, Tan Dinh, Amir Fanai, David Holstius, Virginia Lau, Minh Nguyen, Stuart Schultz, David Fairley

From: Phil Martien

Subject: Global Warming Potentials: Which Values to Use?

Purpose

Since 1996, the Intergovernmental Panel on Climate Change (IPCC) has released at least five sets of global warming potential (GWP) values. The latest set released in the 2013 Fifth Assessment Report (AR5) provided GWPs as before, but also provided GWPs with "carbon-climate feedbacks," effectively providing two sets of GWPs. Which set of GWPs should the Air District use? The purpose of this memo is to present GWP options and make a recommendation.

The Background section of this memo describes GWP basics, including carbon-climate feedbacks, and lists ways GWPs are used at the Air District. The GWP Options section presents a list of GWPs released and highlights what other agencies are using. The Recommendation section makes a recommendation on which GWPs the Air District should use.

Background

Different types of greenhouse gases (GHGs)—for example, CO_2, methane (CH_4), and nitrous oxide (N_2O)—absorb infrared radiation to varying degrees. When summing or comparing GHG emissions, the IPCC recommends using GWPs to represent a mixture of GHGs in terms of its CO_2 equivalence (CO_2eq). GWPs provide a measure of the forcing impacts of a particular greenhouse gas over a period of time *relative* to the forcing from CO_2.[15] GWP values then allow us to compare the impacts of emissions of different gases because they normalize GHGs in terms of their potential to warm the atmosphere.

The relationship between mass of a gas emitted and mass of CO_2eq emitted is expressed as follows: *mass CO_2eq emitted = (mass of gas emitted) x (GWP)*.

Three main factors that determine the GWP value of a GHG:

- the gas' level of absorption of infrared radiation,
- the wavelengths of infrared radiation the gas absorbs, and
- the atmospheric lifetime of the gas.

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[15] The GWP for CO_2 is equal to one (1).

GWP values are usually used for compounds that have a long atmospheric lifetime (years). These compounds last long enough to mix evenly throughout the atmosphere. Some important gases with relatively long atmospheric lifetimes include CO_2, CH_4, N_2O, HFCs, PFCs, SF_6 and NF_3. Short-lived gases such as water vapor, carbon monoxide (CO), tropospheric ozone, other ambient air pollutants (such as NO_x and non-methane VOCs), and aerosols (such as SO_2 products and black carbon) vary spatially, and consequently it is more difficult to quantify their global radiative forcing impacts. Most GHG emission inventories do not include these short-lived compounds. However, IPCC does provide GWPs for them and they could be considered, for example in determining climate benefits (and disbenefits) of particulate matter (PM) controls.

Almost everyone who reports GHGs uses 100-year GWP values. These values assume a time horizon of 100 years in considering the warming potential of gases. However, the IPCC also provides 20-year GWPs. For some policy analyses, a 20-year time horizon is more appropriate than a 100-year horizon. For example, to reduce global warming as soon as possible, we seek measures with meaningful short-term benefits while we work to develop longer-term policies.

In addition to updating GWP values as reported previously, the IPCC's latest assessment report (AR5) also provides GWP values that account for two kinds of feedback effects. IPCC concludes that including feedback effects is likely to give a more accurate estimate of climate impacts from GHG emissions like methane. The first feedback effect accounts for the diminishing ability of oceans and soils to absorb carbon dioxide as the climate warms. For example, as methane emissions warm the climate, some CO_2 that historically would have been absorbed by the land and ocean remains in the atmosphere, causing additional warming. The second feedback effect accounts for the production of additional CO_2 as GHGs are oxidized in the atmosphere. For example, each molecule of methane is eventually oxidized to a molecule of CO_2. This seems like an obvious effect that should be included in a compound's GWP but, without this second feedback effect, it is not.[16]

The Air District uses (or will soon use) GWPs in the following ways:

1. Permitting facilities and charging annual permit fees,
2. Reporting regional GHG emissions and comparing totals to State and national GHG inventories,
3. Determining GHG levels from the Air District's regional GHG measurement network (under development),
4. Forecasting GHG emissions to track progress toward meeting regional targets,
5. Estimating GHG reduction benefits from proposed new regulations or policies.

GWP Options

As more is learned about how GHGs are likely to heat the atmosphere, the IPCC issues updates to GWPs in its assessment reports. The science is evolving,[17] so releasing

[16] This explains, for example, why CO hasn't been counted as a GHG. In light of this second effect, compounds that oxidize to CO_2 should have a GWP at least equal to the number of CO_2 molecules they generate.

[17] According to the IPCC, GWPs typically have an uncertainty of roughly ±35 percent, though some GWPs have larger uncertainty than others.

improved estimates of GWPs is consistent with sound scientific reporting practice. Using the latest science to report emissions will likely result in better policy decisions.

However, the updates to GWP values published by the IPCC can lead to confusion. New releases of GWPs create the potential for inconsistent reporting among reporting agencies. Moreover, it changes an emissions inventory for reasons that have nothing to do with real changes in activity or technology changes.[18]

Table 1 lists GWP values released by the IPCC for some important GHG compounds.

- The Air District has been using IPCC's 1996 GWPs (shown in **bold**).
- Within the past year or two, The California Air Resources Board (ARB), U.S. Environmental Protection Agency (USEPA), and the United Nations Framework Convention on Climate Change (UNFCCC) have shifted from the 1996 GWPs and adopted the 2007 IPCC AR4 GWP values (highlighted in red).
- Highlighted in green are the most recent values from the 2013 IPCC AR5, with feedback effects included.
- Highlighted in blue are 2013 IPCC AR5 values without the feedback effects.

Table 1. GWP Values (100 year horizon) from the IPCC for selected GHGs.

Carbon dioxide (CO_2)	1[a] 1[b] 1[c] 1[d] **1[e]**	Methane (CH_4)	34[a] 28[b] 25[c] 23[d] **21[e]**	Nitrous oxide (N_2O)	298[a] 265[b] 298[c] 296[d] **310[e]**
HFC-134a (hydro-fluorocarbon)	1,550[a] 1,300[b] 1,430[c] 1,300[d] **1,300[e]**	CFC-11 (chloro-fluorocarbon)	5,350[a] 4,660[b] 4,750[c] 4,660[d] **3,800[e]**	Sulfur hexafluoride (SF_6)	26,000[a] 23,500[b] 22,800[c] 22,200[d] **23,900[e]**

a. 2013 IPCC AR5 with feedback effects (See Chapter 8 of Working Group I report, and Supplemental Materials)
b. 2013 IPCC AR5(See Chapter 8 of Working Group I report)
c. 2007 IPCC AR4 (See Chapter 2 of Working Group I report)
d. 2001 IPCC TAR (See Chapter 6 of Working Group I report)
e. 1996 IPCC SAR (See Chapter 2 of the Working Group I report)

The following considerations led to the development of Air District options for applying GWPs:

[18] The situation is analogous to that from changes in the guidance for estimating risks from toxic air contaminants from CalEPA's Office of Environmental Health Hazard Assessment (OEHHA): changes in risk occur because of changes in methods, not because of changes in levels of air toxics.

- Few agencies continue to use the 1996 GWPs and the science behind them is out of date. The only merit in continuing to use these is that it they consistent with what the Air District has done in the past.
- No agencies seem to have adopted the 2001 GWP values and the science behind them is also out of date.
- The 2007 AR4 GWPs have recently been adopted by ARB, USEPA, and UNFCCC.
- The 2013 AR5 GWPs without feedback effects have, so far, not been as widely adopted as the AR4 GWPs and are less likely to accurately represent warming potentials compared to the 2013 AR5 GWPs with feedback effects.
- The 2013 AR5 GWPs with feedback effects are recommended by the IPCC as providing the best information on global warming potentials.

After reviewing IPCC's latest Assessment Report on GWPs, reading policy documents by USEPA, and speaking to the Manager of the Emission Inventory Analysis Section at ARB, I suggest the following two options as reasonable choices for the Air District:

Option 1: Use the most recent science and adopt the 2013 AR5 GWPs with feedback effects. IPCC recommends this as the current best information. Because the 2015 AR5 values include feedback effects, this option best lends itself to understanding benefits of reducing non-CO_2 GHG and also short-lived pollutants, such as black carbon and CO.

Option 2: Use the 2007 AR4 GWPs, which do not include feedback effects. ARB, US EPA, and UNFCCC currently use these GWP values.

With either Option 1 or 2, the Air District would use 100-year GWPs for most purposes, but use 20-year GWPs for analyses of near-term benefits.

Recommendation

Options 1 and 2 each have merit. The choice is one of best information for the Air District versus methodological consistency with other agencies. The most recent GWP values provide the most up to date representation of the global warming effect of GHG emitting activities. Yet, the adoption of new GWP values has been fairly slow and cautious, as national and international agencies emphasize consistency among reporting parties' inventories over more accurate representation. While eventually, it is likely that that the adoption of AR5 GWPs will become best practice, for now major players are sticking to the older AR4 GWPs to be consistent with each other. In addition to consistency with others, there is also an argument made in some USEPA policy documents for consistency with past practice. Since past trends are recalculated with the adoption of new GWPs and since targets are expressed in terms of historical GHG levels, the argument for consistency with past practice is less compelling than that for consistency with others.

The change in the total GHG emissions inventory from using AR5 with feedback effects versus AR4 introduces a difference of a few percent in the reported GHG total. Because CO_2 represents the majority of the inventory[19] and because GWPs only change the non-CO_2 portion of the inventory, differences in emission totals are modest. Tolerating a

[19] About 90% of the CO_2eq total, but dependent on the GWPs applied.

modest level of discrepancy between, for example, how the Air District reports and how ARB reports seems worth the benefit of adopting methods that will more accurately reflect the impacts of non-CO_2 compounds.

Better representation of the climate impacts of non-CO_2 compounds will help Air District staff develop a better understanding of the regional GHG inventory and develop more informed regulations and policies to reduce GHGs. **For this reason I recommend adopting Option 1**.