Draft Scoping Plan Scenario & Alternatives Modeling Description

Draft: December 1, 2016

This document summarizes the input assumptions and data sources for the Reference Scenario, Draft Scoping Plan Scenario, Alternative 1 (No Cap-and-Trade) and Alternative 2 (Carbon Tax) developed as part of the Discussion Draft – 2030 Target Scoping Plan Update.

These are preliminary scenarios developed by the California Air Resources Board (ARB) and implemented by Energy and Environmental Economics, Inc. (E3) in the California PATHWAYS model.[1]

NOTE: The scenarios and modeling assumptions are subject to change for the Draft 2030 Target Scoping Plan in response to stakeholder comments and other technical refinements.

[1] For background about the PATHWAYS model, see the January 15th, 2016 ARB Scoping Plan Update Economic Analysis Workshop presentation on PATHWAYS available here: https://www.arb.ca.gov/cc/scopingplan/meetings/1142016/e3pathways.pdf as well as supporting materials posted here: https://www.arb.ca.gov/cc/scopingplan/meetings/meetings.htm

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Scenario Overview

Three main scenarios are modeled in PATHWAYS:

1) **Reference Scenario,** which represents current policies prior to the passage and implementation of California Senate Bill 350 (SB 350, De Leon, 2015).
2) **Draft Scoping Plan Scenario**, which represents current policies and programs, including the impacts of SB 350, as well as an additional measure to reduce emissions from the refining sector. The PATHWAYS scenario does not model the impacts of cap-and-trade, but this policy is assumed to deliver GHG emissions reductions through a declining cap to help meet the 2030 GHG target. The impact of the cap-and-trade program will be modeled outside of PATHWAYS in the economic analysis of the 2030 Target Scoping Plan. The **Alternative 2 Scenario** is identical to the Draft Scoping Plan Scenario in the PATHWAYS model, but is assumed to use a carbon tax rather than cap-and-trade to deliver the remaining reductions to achieve the 2030 target. The impact of the carbon tax, including estimated cost and GHG reduction, will be modeled outside of PATHWAYS in the economic analysis of the 2030 Target Scoping Plan.
3) The **Alternative 1 Scenario** includes all of the policies and programs that exist in the Draft Scoping Plan Scenario, as well as additional measures to meet the 2030 target without reliance on cap-and-trade or a carbon tax. The types of actions in this scenario may be described as enhancements to existing statutes or other requirements. These descriptions are not to advocate for changes to existing statute, but rather to describe increased action of the type already called for by the existing statute. For example, a 60% RPS in this scenario is to illustrate the need for more renewable power than called for by SB 350.

These scenarios are summarized at a higher level in the table below, and described in more detail in the sections below. Some of the specific modeling assumptions are illustrative of the types of actions that could be undertaken to achieve a policy and do not denote the specific actions that will be undertaken. Note that none of the scenarios currently include assumptions about sources and sinks of greenhouse gas emissions from natural and working lands; research is ongoing in this area and as such, is not part of the PATHWAYS modeling at this time.

Modeling assumptions and inputs are subject to change for subsequent versions of the 2030 Target Scoping Plan.

	Reference	Draft Scoping Plan & Alternative 2	Alternative 1
Energy Efficiency	2015 IEPR Mid-AAEE	2.5x 2015 IEPR Mid-AAEE	
Electrification of buildings	No new electrification		Heat pumps for new water heater and HVAC; Early retirement of some HVAC; Replacement with heat pumps
Electricity Supply	33% RPS by 2030; 18 GW behind the meter PV in 2030	50% RPS by 2030; 28 GW behind the meter PV in 2030	60% RPS by 2030; 28 GW behind the meter PV in 2030
Transportation	Vision model Current Control Program scenario 3.0 million ZEVs by 2030	Vision model Clean Fuels & Technology Scenario, and expanded heavy duty ZEV scenario, Sustainable Freight Strategy 4.2 million ZEVs by 2030	Vision model Clean Fuels & Technology Scenario plus 500-600K additional ZEVs in South Coast Early retirement of 1M pre-2015 ICE LDVs by 2030 4.7 million ZEVs by 2030
Low Carbon Fuel Standard	10% reduction in carbon intensity by 2030	18% reduction in carbon intensity by 2030	25% reduction in carbon intensity by 2030
Res., Com. & Industrial Pipeline Gas	No renewable gas		5% renewable gas by 2030 (modeled as flexible H_2 production)
Refining	No new measures	20% reduction in energy demand by 2030	30% reduction in energy demand by 2030

	Reference	Draft Scoping Plan & Alternative 2	Alternative 1
Industrial & Oil and Gas Extraction	No new measures		25% reduction in energy demand by 2030
Non-Energy GHGs	Current practice in Short-Lived Climate Pollutant Strategy	Mitigation scenario in Short-Lived Climate Pollutant Strategy	
Carbon Pricing	Not modeled	Not modeled in PATHWAYS but assumes cap-and-trade in Draft Scoping Plan or Carbon Tax in Alternative 2 Scenario	None assumed or modeled

Electricity and Natural Gas Energy Efficiency and Building Electrification

Energy efficiency in buildings and industry is implemented in the PATHWAYS model in one of three ways:

1) As new HVAC, building shell or end use technology used in the residential and commercial sectors (e.g., a greater share of high efficiency appliances is assumed to be purchased). New equipment is typically assumed to replace existing equipment "on burn-out", e.g., at the end of the useful lifetime of existing equipment. However, early replacement or early retirement can also be modeled, whereby existing equipment is assumed to be replaced with a more efficient alternative before the end of its useful life (as demonstrated in Scoping Plan Alternative 1).
2) As a reduction in energy services demand, due to conservation or behavior change, and
3) For the sectors that are not modeled using specific technology stocks (industrial and agriculture), energy efficiency is modeled as a reduction in total energy demand.

Since the model is based on a bottom-up forecast of technology stock changes in the residential and commercial sectors, the model does not use a single load forecast or energy efficiency savings forecast as a model input. The data sources for baseline technology shares, performance characteristics and costs are described in the "key data sources" section of this report.

Reference Scenario

The Reference Scenario electricity and natural gas demand are benchmarked to the California Energy Demand 2016 – 2026 Adopted Forecast "mid-case" including Additional Achievable Energy Efficiency (AAEE). The benchmarking is accomplished by changing the composition of new sales of technologies and equipment in the California PATHWAYS model as described above.

Draft Scoping Plan Scenario

In the Draft Scoping Plan Scenario, the SB 350 goal of doubling Additional Achievable Energy Efficiency (AAEE) by 2030 is met. Relative to the California Energy Demand 2016 – 2026 Adopted Forecast, electric energy efficiency is 2.5 times higher than the 2015 IEPR AAEE. Updates to the modeling will align these actions with the requirements of SB 350, which required a doubling, not a 2.5 times increase, in energy efficiency savings. The combined effect of these efficiency measures currently result in 61,460 GWh of electric efficiency savings by 2030 relative to Baseline electricity demand.[2] This is compared to approximately 24,379 GWh of electric energy efficiency savings estimated by 2030 using the 2015 IEPR Additional Achievable Energy Efficiency estimate.

This scenario does not include fuel-switching of natural gas or diesel end uses to electric end-uses. Efficiency measures are included in residential and commercial buildings, industry, agriculture, and street lighting. Energy efficiency measures include:

- Residential
  - Between 2016 and 2035, the share of new residential electric water heaters that are high efficiency increases from 5% in 2025 in the Reference Scenario to 100% in 2035 in the Draft Scoping Plan Scenario.
  - Between 2016 and 2035, the share of new residential central air conditioners that are high efficiency increases from 5% in 2025 in the Reference Scenario to 100% in 2035 in the Draft Scoping Plan Scenario.
  - The share of new residential gas clothes driers that are high efficiency increases from 30% in 2035 in the Reference Scenario to 100% by 2025 in the Draft Scoping Plan Scenario.
  - Between 2016 and 2030, the share of residential refrigerators that are high efficiency increases from 60% in 2025 in the Reference Scenario to 100% by 2030 in the Draft Scoping Plan Scenario.

[2] Baseline electricity demand is calibrated to the California Energy Demand 2016 – 2026 Adopted Forecast "mid-case" and does not include Additional Achievable Energy Efficiency.

- Several types of lighting are modeled in the residential sector: lamps, torchiers, linear fluorescents and reflectors. In the residential sector, by 2030, 68% of new sales of lighting are high efficiency LEDs. In the commercial sector, lighting types include: lamps, linear fluorescents, outdoor and high intensity discharge. In the commercial sector, by 2030, 75% of new sales of lighting are high efficiency LEDs.
- 5% improvement in the electric efficiency of "other" equipment such as televisions and cable set top boxes by 2050 relative to the Reference Scenario.

- Commercial
  - Between 2020 and 2035, the share of new commercial natural gas water heaters that are high efficiency increases from 20% in 2020 in the Reference Scenario to 100%. In addition, 75% of commercial electric water heater sales are high efficiency heat pump water heaters by 2035 in this scenario.
  - Between 2020 and 2035, the share of electric space heating in the commercial sector that are high efficiency heat pumps increases from 0% to 90%.
  - Between 2016 and 2025, the share of new commercial electric cooking ranges that are high efficiency increases from 5% to 100%.
  - Commercial lighting efficiency improvements include an increase in the sale of LED lamps from 15% by 2025 in the Reference Scenario to 100% by 2040 in the Draft Scoping Plan Scenario.
  - Between 2016 and 2025, the share of new commercial refrigerators that are high efficiency increases from 15% in the Reference Scenario to 100% in the Draft Scoping Plan Scenario.
  - Between 2016 and 2025, the share of new commercial ventilation that are high efficiency increases from 33% in the Reference Scenario to 100% in the Draft Scoping Plan Scenario.
- Industry, Street Lighting, Agriculture
  - 17% efficiency improvement in industrial process cooling & refrigeration between 2016 and 2030 relative to business-as-usual (BAU).
  - There is a 75% efficiency improvement in street lighting
  - 68% improvement in agricultural lighting between 2016 and 2050 due to LED adoption.

There are additional efficiency improvements in commercial and residential "other" end-uses including plug-loads such as computers, televisions, cable set-top boxes and other electronics. Total efficiency is assumed to increase by 33%, increasing linearly between 2016 and 2050.

In addition, there are additional electric efficiency savings associated with an increase in water conservation in the Draft Scoping Plan Scenario compared to the Reference Scenario.

In addition to appliance technology substitution, there are also service demand reductions/behavior change measures which are currently assumed to have zero cost, such as:

- 10% reduction in water heating demand by 2020 in the residential sector and by 2024 in commercial sector due to urban water efficiency measures.
- 3% reduction in residential heating load due to behavior change by 2024 (i.e., change in thermostat set point).
- 3% reduction in residential cooling load from improved windows and 1.4% reduction from behavioral change by 2024 (i.e., change in thermostat set point).
- 2% reduction in residential lighting service demand by 2024 due to behavior change (i.e., turning off lights when not in use).

Alternative 1 Scenario

The Alternative 1 Scenario inherits all the above measures. In addition, it includes building electrification in end uses that currently use natural gas with the introduction of high efficiency electric heat pumps in water heating, space heating, and air conditioning. Moreover, approximately 1.2 million residential space heaters and 358 thousand residential air conditioners are retired before the end of their useful lifetimes by 2030 and replaced with higher efficiency heat pumps. In the commercial sector, early retirement of space heating affects 12% of total space heating energy demand by 2030, and 3% of commercial air conditioning by 2030, replaced with high efficiency heat pumps. Furthermore, there is incremental energy efficiency in commercial space heating. Early retirement measures include:

- Between 2025 and 2030, 6% per year of natural gas, distillate, and LPG residential space heaters and air conditioners from 2013 or older are retired early and replaced with electric heat pumps. This measure results in approximately 1.2 million early retirements of residential space heaters (radiators and furnaces) by 2030 and 358 thousand early retirements of residential air conditioners by 2030.
- Between 2025 and 2030, 6% per year of commercial space heaters and air conditioners from 2013 or older are retired early and replaced with electric heat pumps. This early retirement measure affects 12% of total commercial space heating energy demand by 2030, and 3% of total commercial air conditioning energy demand by 2030.

Electrification and efficiency measures in this scenario include:

- Between 2020 and 2035, the proportion of new residential water heater sales that are electric heat pumps increases from 0 to 75%.
- Between 2020 and 2035, the proportion of new residential space heater (radiators and furnaces) sales that are electric heat pumps increases from 0 to 75%.
- Between 2020 and 2035, the proportion of new residential central air conditioner sales that are high efficiency electric heat pumps increases from 0 to 100%.
- Between 2020 and 2035, the proportion of new commercial water heater sales that are electric heat pumps increases from 0 to 75%.
- Between 2020 and 2035, the proportion of new commercial space heater sales that are electric heat pumps increases from 0 to 75%.
- Between 2020 and 2035, the proportion of retiring commercial reference central air conditioner sales being replaced with high efficiency electric heat pumps increases from 0 to 100%.

Electricity Supply

In the electricity sector, two of the major scenario inputs include the percentage of renewable generation that must serve retail sales (modeled as an RPS), and the megawatts of behind-the-meter solar PV online in each year. Behind-the-meter solar PV and the RPS measures interact with each other, in that the rooftop solar reduces retail sales but is not assumed to count towards the RPS. There are many other electricity sector input assumptions as well which also have an impact on costs and emissions, as discussed in this section, although many of these input assumptions are constant across the scenarios. The model calculates hourly electricity supply relative to hourly electricity demand, considering the impact of electrification, demand response, flexible loads and flexible electric vehicle charging, energy storage and flexibility in hydropower production and imported power. As a post-processing step in the model, total renewable curtailment is calculated and additional renewable capacity is added to the model, to ensure that the specified RPS target is met in each scenario, after taking curtailment into account.

Reference Scenario

The Reference Scenario is characterized by the following:

- The Renewable Portfolio Standard is 33% of retail sales by 2020, held constant through 2050.
- Renewable portfolios are based on the CPUC RPS Calculator version 6.2 through 2030 (http://www.cpuc.ca.gov/RPS_Calculator/). Renewables are assumed to be built largely in-state and to require full capacity delivery service for the purposes of transmission development and pricing.

- Behind-the-meter solar photovoltaic (BTM PV) is assumed to reach 18.2 GW statewide by 2030, based on an extrapolation of the California Energy Demand 2016 – 2026 Adopted Forecast mid-case.
- Diablo Canyon is retired by 2025.
- Frequency response requirements, not including frequency response provided by existing hydroelectricity, are assumed to be 376 MW throughout the analysis period. In the Reference Scenario, this requirement must be met with thermal generation.
- The Reference Scenario includes an increase of approximately 115 cumulative MW of conventional, load shedding demand response through 2024, over and above the approximately 2,000 MW of existing demand response available in 2015.
- The Reference Scenario reflects existing pumped hydro storage capacity, as well as the CPUC energy storage mandate of 1.325 GW by 2020. The energy storage mandate is implemented in the model as a mixture of 2-hour, 5-hour and 8-hour batteries.
- Net exports of electricity from California to neighboring jurisdictions are capped at 1,500 MW in each hour throughout the analysis period.
- Existing combined heat and power (CHP) is assumed to remain constant throughout the analysis period in the Reference Scenario. There is no new CHP development in this scenario.

<u>Draft Scoping Plan Scenario</u>

The Draft Scoping Plan Scenario inherits all the above measures in the Reference Scenario. In addition, this Scenario includes:

- The Renewable Portfolio Standard is 50% of retail sales by 2030, increasing to 80% by 2050.
- Renewable portfolios are based on the CPUC RPS Calculator version 6.2 through 2030. Renewables are assumed to be built both in-state and across the West. For the purposes of transmission development and pricing, renewable developments are assumed to require energy-only deliverability rather than full capacity delivery service.
- Behind-the-meter solar photovoltaic (BTM PV) is assumed to reach 28.4 GW statewide by 2030, based on an extrapolation of the California Energy Demand 2016 – 2026 Adopted Forecast high rooftop PV scenario. Updates to the modeling will align the BTM PV assumptions with the Reference Scenario, bringing total BTM PV to 18.2 GW statewide by 2030.
- Frequency response requirements are assumed to be 376 MW throughout the analysis period. In the Draft Scoping Plan Scenario, this requirement can be met with energy storage or thermal generation.

- In the Draft Scoping Plan, rate design changes are assumed to result in the participation of flexible loads on the grid to help balance renewable generation. By 2018, 10% of residential and commercial electric water heating, space heating, air conditioning, and refrigeration are assumed to be capable of operating flexibility, providing between 2 to 3 hours of shifted load. In addition, by 2018, one half of electric light duty vehicles are assumed to have access to "smart charging", such that over the course of 12 hours, vehicle charging needs can be shifted to help integrate renewables on the grid.
- By 2030, one half of light-duty electric vehicles are assumed to have access to workplace charging, enabling greater use of day-time charging of electric vehicles.
- The Draft Scoping Plan Scenario includes an increase of approximately 5,500 cumulative MW of conventional, load shedding demand response by 2031, over and above the approximately 2,000 MW of existing demand response available in 2015. This quantity of demand response is not optimized for the scenario but reflects prior state goals to increase the availability of demand response.
- In the Draft Scoping Plan Scenario, a limited quantity of existing CHP in the commercial, industrial, oil and gas, TCU and refining sectors is assumed to retire and not be replaced starting in 2031. There is no new CHP development in this scenario.

Alternative 1 Scenario

The Alternative 1 Scenario inherits all the above measures in the Draft Scoping Plan Scenario. In addition, the Renewable Portfolio Standard is 60% of retail sales by 2030, increasing to 80% by 2050.

Transportation

Reference Scenario

On-road transportation vehicle stocks, vehicle miles traveled, and fuel efficiency in the Reference Scenario are calibrated to match the Current Control Programs scenario presented in the 2016 California Mobile Source Strategy report.[3] This Current Control Programs scenario was developed using the California Air Resources Board's Vision 2.1 scenario-planning model[4] which provided PATHWAYS with data inputs for vehicle stock, vehicle miles traveled (VMT), and vehicle efficiency assumptions. The Vision model in turn draws these values from EMFAC2014, with some modifications designed to incorporate policies and technological parameters not accounted for in EMFAC (e.g., extra VMT reductions to account for the impacts of the SB375).[5] The Reference

[3] https://www.arb.ca.gov/planning/sip/2016sip/2016mobsrc.htm
[4] https://www.arb.ca.gov/planning/vision/vision.htm
[5] For an account of how the EMFAC inputs were modified and built upon in Vision, see pages 8-10 of the Vision 2.0 General Model Documentation (released October 2015). Complete documentation has not yet

Scenario is designed to reflect the transportation policy environment prior to the passage of SB 350. Among other policies, the Reference Scenario incorporates:[6]

- The effects of SB375 and its associated Sustainable Communities Strategy and Regional Transportation Plan documents, expressed through Municipal Planning Organization (MPO) -specific reductions to VMT
- The California ZEV Action Plan to get 1.5 million zero-emissions vehicles (ZEVs) on the road by 2025, including plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs), and hydrogen fuel cell electric vehicles (FCEVs), expressed through fleet composition trajectories[7]
- The Low-Carbon Fuel Standard (discussed in the section on transportation biofuels)

Calibration to the Vision Current Control Programs scenario values is accomplished in PATHWAYS through a series of measures that determine which vehicles replace retiring vehicles that have reached the end of their lifetimes. Between 2015 and 2030, these measures increase the total number of ZEVs from 0.1 million in 2015 to about 3 million in 2030. Tables 1, 2 and 3 show the composition of the Reference Scenario light-duty (LDV), medium-duty (MDV), and heavy-duty vehicle (HDV) fleets in 2015, 2025, and 2030.

Table 1. Reference Scenario light-duty vehicle fleet composition
(components may not sum to total due to rounding)

Vehicle Type (millions)	2015	2025	2030
Gasoline	25.3	25.9	26.8
BEV	0.02	0.45	0.78
Hydrogen	0.01	0.20	0.44
PHEV	0.07	1.03	1.75
Total	25.4	27.6	29.7

been published for Vision 2.1, but a list of additional modifications to the EMFAC inputs added between 2.0 and 2.1 can be found in the Vision Model Update Memo published in May 2016.

[6] For an expanded list of regulations included in the Vision Baseline/Current Control Programs scenario, see page 159 of the Mobile Source Strategy report.

[7] https://www.gov.ca.gov/docs/2016_ZEV_Action_Plan.pdf

Table 2. Reference Scenario medium-duty vehicle fleet composition
(components may not sum to total due to rounding)

Vehicle Type (thousands)	2015	2025	2030
Gasoline	632	363	358
Diesel	716	827	845
Total	1,347	1,190	1,203

Table 3. Reference Scenario heavy-duty vehicle fleet composition
(components may not sum to total due to rounding)

Vehicle Type (thousands)	2015	2025	2030
Diesel	246	310	344
CNG	9	15	17
Total	255	326	361

Table 4. Reference Scenario bus fleet composition
(components may not sum to total due to rounding)

Vehicle Type (thousands)	2015	2025	2030
Gasoline	25	32	36
Diesel	31	30	31
CNG	5	5	5
Total	61	67	72

The PATHWAYS model also includes assumptions for off-road transportation, but specific technology stocks and vintages are not modeled for off-road vehicles. The off-road transportation categories modeled include: aviation, passenger rail, freight rail, ocean-going vessels and harbor craft. Energy demand in these sectors is calibrated to reflect the ARB emissions inventory and projected forward based on historical trends. There are no emission reductions measures in the Reference Scenario for off-road transportation.

Draft Scoping Plan Scenario

In the Draft Scoping Plan Scenario, VMT, vehicle fuel efficiency, and on-road light duty vehicle fleet composition are calibrated to the Vision Cleaner Technologies and Fuels scenario, which is described in the 2016 Mobile Source Strategy. Medium and heavy duty vehicle fleet compositions are based on the expanded heavy duty ZEV beyond Cleaner Technologies and Fuels scenario as described in the 2016 Mobile Source Strategy. This scenario reflects the impacts of SB 350 among other policies.

For on-road vehicles, this scenario includes reductions in light-duty VMT, increases in gasoline and diesel vehicle efficiency, and additional adoption of ZEV technologies. In addition, there are emission reductions assumed from off-road subsectors such as aviation, rail and ocean-going vessels which reflect the guidance in the California Sustainable Freight Action Plan.

Alternative vehicle measures include:

- In the light-duty vehicle fleet:
  - PHEVs increase to 8.2% of the fleet in 2030 from 5.9% in the Reference Scenario, an increase of 686,000 PHEVs
  - BEVs increase to 3.7% of the fleet in 2030 from 2.6% in the Reference Scenario, an increase of 309,000 BEVs
  - FCEVs increase to 2.2% of the fleet in 2030 from 1.5% in the Reference Scenario, and increase of 203,000 FCEVs

In the medium-duty fleet, FCEV, CNG, and BEV vehicles are introduced and displace a portion of the gasoline and diesel vehicles that make up the Reference MDV fleet:

  - FCEVs make up 0.3% of the fleet in 2030, about 3,700 vehicles
  - CNG trucks make up 6.2% of the fleet in 2030, about 75,000 vehicles
  - BEVs make up 2.7% of the fleet in 2030, about 33,000 vehicles

In the heavy-duty fleet, electric and hydrogen trucks are introduced and displace a portion of the diesel and CNG vehicles that make up the Reference HDV fleet:

  - BEVs make up 0.5% of the fleet in 2030, about 1,900 vehicles
  - FCEVs make up 0.1% of the fleet in 2030, about 200 vehicles

In the bus fleet, electric buses are introduced and CNG is partially phased out:

  - BEVs make up 4.4% of the fleet by 2030, about 3,100 vehicles
  - CNG trucks decrease to 5.3% of the fleet in 2030 from 7.3% in the Reference Scenario, a decrease of about 1,500 trucks

Table 5. Draft Scoping Plan Scenario light-duty vehicle fleet composition (components may not sum to total due to rounding)

Vehicle Type (millions)	2015	2025	2030
Gasoline	25.3	25.9	25.6
BEV	0.02	0.45	1.09
Hydrogen	0.01	0.20	0.64
PHEV	0.07	1.03	2.44
Total	25.4	27.6	29.7

Table 6. Draft Scoping Plan Scenario medium-duty vehicle fleet composition
(components may not sum to total due to rounding)

Vehicle Type (thousands)	2015	2025	2030
Gasoline	632	364	348
Diesel	715	787	742
BEV	0	9	33
CNG	0	30	75
Hydrogen	0	1	4
Total	1,347	1,190	1,203

Table 7. Draft Scoping Plan Scenario heavy-duty vehicle fleet composition
(components may not sum to total due to rounding)

Vehicle Type (thousands)	2015	2025	2030
Diesel	246	308	337
BEV	0	1	2
CNG	9	17	22
Hydrogen	0	0.1	0.2
Total	255	326	361

Table 8. Draft Scoping Plan Scenario bus fleet composition
(components may not sum to total due to rounding)

Vehicle Type (thousands)	2015	2025	2030
Gasoline	24	31	32
Diesel	31	30	33
BEV	0	2	3
CNG	6	4	4
Total	61	67	72

On-road service demand reduction measures from the Vision Cleaner Technologies and Fuels scenario include a 5% reduction in light-duty VMT in 2030 compared to the Reference Scenario, with VMT reductions first starting in 2020.

Efficiency and cleaner fuels measures in the PATHWAYS model for off-road subsectors include:

- A 70% reduction in jet fuel demand for aviation from BAU based on the FAA CLEEN program, beginning at 0% in 2016 and saturating in 2050

- 4% of passenger and freight rail diesel use is converted to electric, starting in 2020 and saturating in 2050
- 45% efficiency improvement in passenger rail and freight rail diesel demand affecting 95% of rail energy use, starting in 2016 for passenger rail and in 2020 for freight rail and saturating in 2050
- 80% of in-port fuel use from ocean-going vessels is electrified by 2050, beginning in 2020
- 40% efficiency improvement of in-transit diesel use for ocean-going vessels by 2050, beginning in 2015
- We assume a conversion of harbor craft energy demand from diesel to electricity, starting in 2020:
    - 6% of harbor craft energy demand is fully electric by 2050
    - 71% of harbor craft energy demand is diesel hybrid by 2050

Alternative 1 Scenario

This scenario adds 550,000 additional light-duty ZEVs to the vehicle fleet by 2030 and introduces early retirement for a portion of pre-2015 vintage gasoline light-duty vehicles.

The additional ZEVs in the Alternative 1 Scenario are phased in between 2024 and 2030. They are distributed between the LDV classes (light-duty autos and light-duty trucks) and the three ZEV technologies (PHEV, BEV, and FCEV) in proportion to their distribution in the Vision Cleaner Technologies and Fuel Scenario. The additional 550,000 ZEVS increase the total light-duty ZEV population to 4.7 million in 2030, an increase of 13% over the Draft Scoping Plan Scenario. See table 9 for the composition of the light-duty fleet in the Alternative 1 Scenario. No changes were made to the MDV, HDV, and bus fleets in this scenario.

The early retirement of light-duty gasoline vehicles is implemented between 2025 and 2030. Approximately 1 million of the 4.5 million pre-2015 vintage gasoline vehicles that are still in service in 2030 in the Draft Scoping Plan Scenario are retired early and replaced with newer, more fuel-efficient gasoline models. Vehicles retired early are not replaced with ZEVs.

Table 9. Alternative 1 Scenario light-duty vehicle fleet composition (components may not sum to total due to rounding)

Vehicle Type (millions)	2015	2025	2030
Gasoline	25.3	25.8	25.0
BEV	0.02	0.46	1.23
Hydrogen	0.01	0.21	0.72
PHEV	0.07	1.12	2.77
Total	25.4	27.6	29.7

Transportation Biofuels and the Low Carbon Fuel Standard

Transportation biofuel assumptions, including the impacts of a post-2020 Low Carbon Fuel Standard (LCFS), were developed by ARB staff using their Biofuel Supply Module. The Biofuel Supply Module (BFSM) uses the PATHWAYS transportation energy demand by scenario as an input. The BFSM then calculates the type and quantity of transportation biofuels that would be cost-effective for consumers relative to fossil fuel prices for gasoline, diesel, and compressed natural gas, given a set of assumptions about biofuel subsidies, LCFS prices, carbon prices and the cost of delivered biofuels. For more information about the biofuel assumptions used in the scenarios, see ARB's Technical Documentation of the Biofuel Supply Module.[8]

The BFSM provides the PATHWAYS model with estimates of annual transportation biofuel supply by type and estimated biomass usage by feedstock, based on each scenario's input assumptions. The quantities of biofuels from the BFSM are then input into the PATHWAYS model.

The PATHWAYS model and BFSM use the same underlying assumptions about biomass resource potential, conversion efficiencies, transport costs and process costs. The BFSM also reflects the impact of LCFS credit prices and California cap-and-trade carbon prices on final, delivered biofuel prices. These market prices are not included in the biofuel prices modeled in PATHWAYS because the LCFS and cap-and-trade programs reflect in-state transfers of costs. As a result, the biofuel costs in PATHWAYS and the BFSM will be different.

Another important distinction between the BFSM and the PATHWAYS model is how the carbon intensity of biofuels are calculated. The PATHWAYS model uses the ARB's emission inventory accounting standard for biofuels, whereby combustion of biofuels are treated as zero-emission fuels and emissions associated with producing fuels and

[8] Biofuel Supply Module Technical Documentation available as part of the materials from the September 14, 2016 CARB Public Workshop on the Transportation Sector to Inform Development of the 2030 Target Scoping Plan Update, available here: https://www.arb.ca.gov/cc/scopingplan/meetings/meetings.htm

feedstocks outside of California are not considered. In contrast, the BFSM applies the LCFS lifecycle emissions accounting framework, which takes into account all GHG emissions (or savings) associated with the production, transportation, and use of a given fuel, whether they occur in-state or out-of-state. For example, avoided greenhouse gas emissions from methane that would have otherwise been released from manure, had the biogas not be captured for use as a fuel, are credited to transportation fuels under the LCFS lifecycle emissions accounting framework. Under the ARB emissions inventory accounting, these avoided methane emissions are reflected in the "non-energy, non-CO2" sector in PATHWAYS rather than as part of biofuels carbon accounting in the transportation fuels sector.

This difference in GHG accounting between the PATHWAYS model and the BFSM is not a problem from an analytical perspective, since the differences reflect how greenhouse gas emissions are allocated between fuels and sectors. However, it is important to keep in mind this distinction in GHG accounting when comparing results across models. For example, while the BFSM may calculate a scenario that has a 20% reduction in the carbon intensity of fuels using the LCFS lifecycle emissions accounting framework, the PATHWAYS model, using the ARB emission inventory framework, will typically show fewer carbon reductions coming from biofuels for the same total quantity of biofuels.

Reference Scenario

The LCFS allowance price assumptions reflect a 10% carbon intensity reduction from 2020 through 2030 in the Reference Scenario. In addition, this scenario assumes:

- An LCFS credit price of $10/ton in 2030
- By 2030, in addition to conventional ethanol and biodiesel, there are 580 million gallons of advanced biofuels in the transportation sector, including cellulosic ethanol, renewable gasoline and renewable diesel (reported on a gallons of gasoline equivalent (GGE) basis, using the lower heating value for gasoline).
- In addition, 100% of compressed natural gas (CNG) for transportation is biogas (2.1% of total pipeline gas).

Draft Scoping Plan Scenario

The LCFS allowance price assumptions reflect an 18% carbon intensity reduction from 2020 through 2030 in the Draft Scoping Plan Scenario. In addition, this scenario assumes:

- An LCFS credit price of $80/ton in 2030
- By 2030, in addition to conventional ethanol and biodiesel, there are 980 million gallons of advanced biofuels in the transportation sector, including cellulosic

ethanol, renewable gasoline and renewable diesel (reported on a GGE basis, using the lower heating value for gasoline)
- In addition, 100% of CNG is biogas (3.2% of total pipeline gas)

Alternative 1 Scenario

The LCFS allowance price assumptions reflect a 25% carbon intensity reduction from 2020 through 2030 in the Alternative 1 Scenario. In addition, this scenario assumes:

- An LCFS credit price of $80/ton in 2030 as well as a renewable diesel credit of $0.70/GGE
- By 2030, in addition to conventional ethanol and biodiesel, there are 2,306 million gallons of advanced biofuels in the transportation sector, including cellulosic ethanol, renewable gasoline and renewable diesel (reported on a GGE basis, using the lower heating value for gasoline)
- In addition, 100% of CNG is biogas (3.6% of total pipeline gas)

Renewable Gas for Residential, Commercial, Industrial and Agricultural Customers

Alternative 1 Scenario

In the Reference and Draft Scoping Plan Scenarios, there is no biogas or renewable gas used by residential, commercial, industrial, or agricultural customers. In the Alternative 1 Scenario, 5% of the energy in the gas pipeline is assumed to be renewable gas by 2030. This renewable gas serves residential, commercial, industrial, and agricultural customers. Renewable gas is introduced into these sectors beginning in 2023. The penetration increases linearly for four years and reaches 1% of pipeline gas in 2026. Each year from 2026 through 2030, an additional 1% of pipeline gas is converted to renewable gas, resulting in renewable gas composing 5% of total pipeline gas in 2030.

The utilization of renewable gas by 2030 is modeled in PATHWAYS as hydrogen blended into the gas pipeline to represent a conservative estimate of the cost for renewable gas; although in practice, renewable gas could be biomethane, renewable hydrogen, or a mixture of the two fuels.

Hydrogen Production

Reference and Draft Scoping Plan Scenario

In the Reference and Draft Scoping Plan Scenario, hydrogen is used as fuel for light duty fuel cell vehicles. The hydrogen is assumed to be produced using 100% grid electrolysis by 2030, with this share increasing linearly from 33% in 2020. The grid electrolysis is assumed to be operated flexibly, with a 25% load factor, such that the hydrogen production helps to integrate solar generation onto the electric grid.

Alternative 1 Scenario

In the Alternative 1 Scenario, hydrogen is used as fuel for light duty fuel cell vehicles and to meet the 5% utilization of renewable gas for residential, commercial and industrial customers. The same assumptions about the production and operation of hydrogen facilities are applied in this scenario as in the Draft Scoping Plan Scenario.

Refining

Due to a calibration difference between the PATHWAYS model and ARB emissions inventory, the PATHWAYS model assumes that total refining emissions are higher and total industrial sector emissions are lower than the ARB Emissions Inventory reports in 2014. This discrepancy is adjusted for in the measure inputs to ensure that total emissions reductions in the refining sector in the PATHWAYS model are correct relative to actual refining emissions from the ARB emissions inventory.

Reference Scenario

No changes in Refining sector energy demand are assumed in the Reference Scenario.

Draft Scoping Plan Scenario

In this scenario, refining emissions are reduced by 5 $MMTCO_2$ relative to business-as-usual by 2030 (20% of present-day emissions).

Alternative 1 Scenario

In this scenario, refining emissions are reduced by 8 $MMTCO_2$ relative to business-as-usual by 2030 (30% of present-day emissions).

Industry and Oil and Gas

Reference Scenario

No changes in Industry and oil and gas sector energy demand are assumed in the Reference Scenario.

Draft Scoping Plan Scenario

Fuel use becomes more efficient in Industry across various end uses. Measures include:

- 15% increase in efficiency for diesel powered boilers and 20% increase in efficiency for pipeline gas powered boilers between 2020 and 2030
- 13% increase in efficiency for diesel use and 30% increase in efficiency for pipeline gas use for process heating between 2016 and 2030
- Improvement in the efficiency of machine drive equipment (e.g. fans, pumps, air motors and compressor controls) through 2050
- Electricity efficiency measures mentioned above for lighting (90% LEDs in the lighting stock by 2050)

There are no measures in Oil and Gas in the Draft Scoping Plan Scenario.

Alternative 1 Scenario

Relative to the above measures, Industrial and Oil and Gas CO_2 emissions are reduced another 25% by 2030. The 25% represents the potential preliminary estimate of reductions across the sector as estimated by ARB using efficiency benchmark data.

Agriculture

The scope of the agriculture sector as described in this section pertains to agricultural fossil fuel CO_2 emissions. Land-use and land change emissions and sinks are not included in this definition. Likewise, other greenhouse gas emissions that are not associated with fossil fuel combustion, such as methane and nitrogen oxides are not included in this definition, but rather appear in the “non-energy, non-CO_2 GHG” category.

Reference Scenario

There are electric and natural gas efficiency improvements assumed in the Reference Scenario, consistent with the 2015 IEPR AAEE building efficiency assumptions described in the section above. These measures result in a 14 to15% efficiency improvement in lighting, motors, refrigeration, water heating and cooling, and other miscellaneous electric and natural gas end-uses by 2024 relative to current practice (Baseline).

Draft Scoping Plan Scenario

There is additional energy efficiency in lighting in the Draft Scoping Plan Scenario, which is described in the energy efficiency section of this report. There are no additional agricultural measures in this scenario.

Alternative 1 Scenario

Agriculture measures are the same as in the Draft Scoping Plan Scenario.

Non-Energy, Non-CO_2 GHGs

The “non-energy, non-CO_2” greenhouse gas sector in PATHWAYS encompasses all GHGs in the ARB California emissions inventory that are not carbon dioxide associated with the combustion of fossil fuels. This category includes methane emissions, F-gases and nitrogen oxides as well as non-fossil fuel based CO_2 emissions associated with the production of cement. The categories of emissions modeled in this sector include:

- Cement
- Waste
- Petroleum refining fugitive emissions
- Oil extraction fugitive emissions

- Electricity generation fugitive emissions and process emissions
- Pipeline fugitive emissions
- Enteric fermentation in agriculture
- Soil emissions in agriculture associated with fertilization
- Manure
- Other agricultural emissions
- F-gases in all sectors, primarily associated with refrigerants, insulation and cooling

Reference Scenario

Emissions in this sector are benchmarked to the ARB 2015 Edition Emission Inventory (covering emission years 2000 – 2013). The growth trajectories for emissions by category are based on the "current practice" scenario described in the ARB Short-Lived Climate Pollutant Strategy.

Draft Scoping Plan Scenario

Non-energy GHG emissions are reduced from business-as-usual per SB 1368, as reflected in the ARB Short-Lived Climate Pollutant (SLCP) Strategy for most categories, and based on prior research in the categories of cement and soil emissions, which are not included in the SLCP Strategy. All measures are currently assumed to begin immediately and to increase linearly through 2030. In modeling updates, the start date for methane reductions from landfill gas and manure will be pushed back to 2020. The percent reductions in GHGs are relative to the baseline emissions in 2030:

Emission reduction measures in this category that are based on prior research of mitigation potential include:

- 9% reduction in cement non-energy emissions due to the use of fly ash and other substitutes
- 22% reduction in soil emissions due to optimized application of fertilizers. Research suggests optimized fertilizer application can lead to significant reductions in emissions of N_2O both directly and indirectly, without affecting crop yields[9]

Measures that are designed to reflect the emission reduction targets in SB 1383, and described in the SLCP Strategy, include:

[9] C.S. Snyder, T.W. Bruulsema, T.L. Jensen and P.E. Fixen (2009) Review of greenhouse gas emissions from crop production systems and fertilizer management effects. Agriculture, Ecosystems and Environment 133: 247-266. And George Silva (2011) Slow release nitrogen fertilizers. Available online http://msue.anr.msu.edu/news/slow_release_nitrogen_fertilizers [Accessed November 6, 2014]

- 14% reduction in waste emissions due to organic diversion of waste
- 45% reduction in petroleum refining and oil and gas fugitive emissions
- 40% reduction in electricity generation fugitive and process emissions
- 45% reduction in pipeline fugitive emissions
- 65% reduction in manure methane emissions
- 16% reduction in enteric fermentation emissions
- 63% reduction in F-gases (high global-warming potential pollutants)

The estimated emissions reductions as modeled in PATHWAYS represent one potential way to achieve the reductions outlined in SB 1383. Emission reduction categories in PATHWAYS do not correspond specifically to the sector targets outlined in SB 1383 and the SLCP Strategy.

Alternative 1 Scenario

The non-energy GHG emissions follow the same trajectory as the Draft Scoping Plan Scenario.

Key Data Sources for Scenarios

Residential

Description	Reference
Calibration of sectoral electricity demand input data (GWh)	California Energy Demand 2016-2026 Adopted Forecast, California Energy Commission, January 2016, CEC-200-2016-001 (15-IEPR-03)
Calibration of sectoral pipeline gas demand input data (Mtherms)	2009 residential gas usage demand from CEC Energy Consumption database and KEMA, 2009. California RASS.
Reference technology shares (% of stock)	Kema, 2009. California RASS. Percent of high efficiency clothes washers based on 2013 Navigant Potential Study. Lighting based on 2010 DOE Lighting Market Characterization Report Tables
Technology inputs including useful life, energy type, and cost assumptions	Data used in support of AEO 2013 from the National Energy Modeling System: Input filenames “rsmlgt.txt” For lighting: Energy Savings Potential of Solid-State Lighting in General Illumination Applications (DOE, 2012)
Subsector energy or service demand consumption estimate used to calibrate total service demand (kWh/household)	KEMA, 2009. California RASS Energy Star Program Requirements and Criteria for Dishwashers

Description	Reference
Per-unit technology costs	Cost projections are taken from data used in support of AEO 2013 from the National Energy Modeling System: Input filenames “rsmlgt.txt” and Input filenames “rsmeqp.txt”. Lighting from the Energy Savings Potential of Solid-State Lighting in General Illumination Applications for LED lamps and luminaires.
Technology efficiencies	Data used in support of AEO 2013 from the National Energy Modeling System: Input filename “rsmshl.txt” and Input filename “rsmeqp.txt”. Adjusted from UEC values taken from "rsuec.txt" and stock efficiencies from "rsstkeff.txt". DOE, 2012. Energy Savings Potential of Solid-State Lighting in General Illumination Applications.

Commercial

Description	Reference
Calibration of sectoral electricity demand input data (GWh)	California Energy Demand 2016-2026 Adopted Forecast, California Energy Commission, January 2016, CEC-200-2016-001 (15-IEPR-03)
Calibration of sectoral pipeline gas demand input data (Mtherms)	California Energy Demand IEPR 2014 - Mid Demand Case
Energy use by technology per square foot	CEUS, 2006. SCE values used for LADWP and "Other" electric service territories. Adjusted for square footage with no cooling. And for lighting: DOE Lighting Market Characterization Report, 2010.
Reference technology shares (% of stock)	Service demand share from National Energy Modeling System: Input filename “ktek.txt” adjusted for service saturation from 2006 CEUS, and for lighting: DOE Lighting Market Characterization Report, 2010.
Technology inputs including useful life, energy type, and cost assumptions	Data used in support of AEO 2013 from the National Energy Modeling System: Input filenames “ktek.txt”.
Subsector energy or service demand consumption estimate used to calibrate total service demand (kWh/sq ft)	CEUS, 2006 and data used in support of AEO 2013 from the National Energy Modeling System: Input filenames “ktek.txt”.

Description	Reference
Per-unit technology costs	Data used in support of AEO 2013 from the National Energy Modeling System: Input filenames “ktek.txt”.
Technology efficiencies	Data used in support of AEO 2013 from the National Energy Modeling System: Input filenames “ktek.txt”.

Transportation

Description	Reference
VMT/Fuel use	• CARB EMFAC 2014 (LDV, MDV, HDV, and Buses) • ARB Vision off-road (passenger rail, freight rail, harbor craft, oceangoing vessels, aviation)
Fuel efficiency	• CARB EMFAC 2014 (MDV, HDV, Buses, LDV motorcycles) • "Transitions to Alternative Vehicles and Fuels", National Academies Press, 2013, Mid case (LDV auto and truck) • ARB Vision off-road (passenger rail, freight rail, harbor craft, oceangoing vessels, aviation)
New Technology	• "Transitions to Alternative Vehicles and Fuels", National Academies Press, 2013 • Assessment of Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles, National Academies Press (2010) https://www.nap.edu/catalog/12845/technologies-and-approaches-to-reducing-the-fuel-consumption-of-medium-and-heavy-duty-vehicles • 2012 MODEL YEAR ALTERNATIVE FUEL VEHICLE (AFV) GUIDE, http://www.gsa.gov/graphics/fas/2012afvs.pdf • Department of Transportation Fuel Cell Bus Life Cycle Model: Base Case and Future Scenario Analysis • "Zero Emissions Trucks." Delft, 2013 • "Advancing Technology for America’s Transportation Future." National Petroleum Council, 2012.
Emissions	• EPA emission factors • CARB refining fuel combustion emissions • APTA 2010 Fact Book, Appendix B

Industrial

Description	Reference
Sectoral electricity demand input data	CEC data used in support of http://uc-ciee.org/downloads/CALEB.Can.pdf

Sectoral pipeline gas demand input data	CEC data used in support of http://uc-ciee.org/downloads/CALEB.Can.pdf
Sectoral "other" energy input data	CARB emissions inventory historical data
End-use energy decomposition by subsector	CPUC Navigant Potential Study, 2013.

Refining

Description	Reference
Sectoral electricity demand input data	California Energy Demand 2016-2026 Adopted Forecast, California Energy Commission, January 2016, CEC-200-2016-001 (15-IEPR-03)
Sectoral pipeline gas demand input data	CEC data used in support of http://uc-ciee.org/downloads/CALEB.Can.pdf. Allocated to gas utility service territories as a function of refinery electricity demand (broken out by electric service territory). Assumed that LADWP and SCE refining demand met by SCG.
Sectoral "other" energy input data. Input	CARB GHG Emissions Inventory. Allocated to gas utility service territories as a function of refinery electricity demand (broken out by electric service territory). Assumed that LADWP and SCE refining demand met by SCG.
End-use energy decomposition by subsector	CPUC Navigant Potential Study, 2013.

Oil and Gas

Description	Reference
Sectoral electricity demand input data	California Energy Demand 2016-2026 Adopted Forecast, California Energy Commission, January 2016, CEC-200-2016-001 (15-IEPR-03)
Sectoral pipeline gas demand input data	CEC data used in support of http://uc-ciee.org/downloads/CALEB.Can.pdf

Transportation Communications and Utilities (TCU)

Description	Reference
Sectoral electricity demand input data	California Energy Demand 2016-2026 Adopted Forecast, California Energy Commission, January 2016, CEC-200-2016-001 (15-IEPR-03)

Description	Reference
Sectoral pipeline gas demand input data	California Energy Demand 2016-2026 Adopted Forecast, California Energy Commission, January 2016, CEC-200-2016-001 (15-IEPR-03)

Agricultural

Description	Reference
Sectoral electricity demand input data	California Energy Demand 2016-2026 Adopted Forecast, California Energy Commission, January 2016, CEC-200-2016-001 (15-IEPR-03)
Sectoral pipeline gas demand input data	California Energy Demand 2016-2026 Adopted Forecast, California Energy Commission, January 2016, CEC-200-2016-001 (15-IEPR-03)
Sectoral "other" energy input data.	Diesel: EIA Adjusted Sales of Distillate Fuel Oil by End Use Gasoline: CARB GHG Emissions Inventory
End-use energy decomposition by subsector	CPUC Navigant Potential Study, 2013.

Water-Related Energy Demand

Description	Reference
Forecast of state water demand	State of California, Natural Resources Agency, Department of Water Resources. "The Strategic Plan." California Water Plan: Update 2013 1 (2013): 26 Feb. 2015. <http://www.waterplan.water.ca.gov/docs/cwpu2013/Final/0a-Vol1-full2.pdf>.
Embedded energy in water	GEI Consultants, and Navigant Consulting. Embedded Energy in Water Studies Study 2: Water Agency and Function Component Study and Embedded Energy- Water Load Profiles. California Public Utilities Commission Energy Division, 5 Aug. 2011. Web. 26 Feb. 2015. <ftp://ftp.cpuc.ca.gov/gopher-data/energy%20efficiency/Water%20Studies%202/Study%202%20-%20FINAL.pdf>.

Description	Reference
Embedded energy in water used for agriculture	Wolff, Gary, Sanjay Gaur, and Maggie Winslow. User Manual for the Pacific Institute Water to Air Models. Rep. no. 1. Pacific Institute for Studies in Development, Environment, and Security, Oct. 2004. Web. 26 Feb. 2015. <http://pacinst.org/wp-content/uploads/sites/21/2013/02/water_to_air_manual3.pdf>.

Electricity

Category	Data source
Hourly end-use electric load shapes	Residential & commercial: Primarily DEER2008 and DEER 2011, BEopt for residential space heating, cooking and other, CEUS for commercial space heating, lighting and cooking. Agriculture & Industrial: PG&E 2010 load shape data
Hourly renewable generation shapes	Solar PV: simulated using System Advisor Model (SAM), PV Watts Concentrated solar power: simulated using System Advisor Model (SAM) Wind: Western Wind Dataset by 3TIER for the first Western Wind and Solar Integration Study performed by NREL http://wind.nrel.gov/Web_nrel/
Hydroelectric characteristics	Monthly hydro energy production data from historical EIA data reported for generating units, http://www.eia.gov/electricity/data/eia923/ Daily minimum and maximum hydro generation limits based on CAISO daily renewable watch hydro generation data http://www.caiso.com/market/Pages/ReportsBulletins/DailyRenewablesWatch.aspx
Import/export limits	Consistent with assumptions used in base case of CA electric utility/E3 study “Investigating a Higher RPS Study” (2013).

Category	Data source
Existing generation & heat rates	TEPPC 2022 Common Case, and "Capital cost review of power generation technologies, recommendations for WECC's 10- and 20-year studies" http://www.wecc.biz/committees/BOD/TEPPC/External/2014_TEPPC_Generation_CapCost_Report_E3.pdf
Renewable generation & transmission capital costs	CPUC RPS Calculator version 6.2
Thermal generation capital costs	"Capital cost review of power generation technologies, recommendations for WECC's 10- and 20-year studies" (E3, March 2014) http://www.wecc.biz/committees/BOD/TEPPC/External/2014_TEPPC_Generation_CapCost_Report_E3.pdf
Energy storage capital costs	"Cost and performance data for power generation technologies," (Black and Veatch, prepared for NREL, February 2012) http://bv.com/docs/reports-studies/nrel-cost-report.pdf
Power plant financing assumptions	"Capital cost review of power generation technologies, recommendations for WECC's 10- and 20-year studies" (E3, March 2014) http://www.wecc.biz/committees/BOD/TEPPC/External/2014_TEPPC_Generation_CapCost_Report_E3.pdf
Current electric revenue requirement	Revenue requirement by component, historical FERC Form 1 data, https://www.ferc.gov/docs-filing/forms.asp

Fossil Fuels

Fossil fuel price forecasts are taken from the EIA's Annual Energy Outlook 2015 reference case scenario. State and federal taxes are excluded.

Produced Fuels

Department of Energy. H2A Analysis. 2014. http://www.hydrogen.energy.gov/h2a_analysis.html (accessed 2014).

Svenskt Gastekniskt Center AB. Power-to-gas -- A Technical Review. Technical Report, Malmo: Svenskt Gastekniskt Center AB, 2013.

Biomass and Biofuels

California Air Resources Board Biofuel Supply Module Technical Documentation for Version 0.83 Beta, available as part of the materials from the September 14, 2016 CARB Public Workshop on the Transportation Sector to Inform Development of the 2030 Target Scoping Plan Update, available here: https://www.arb.ca.gov/cc/scopingplan/meetings/meetings.htm

Non-energy, Non-CO2 Greenhouse Gases

Variable	Description
Categories of non-energy, non-CO2 greenhouse gases	Subsector GHG emissions data from CARB's emissions inventory by IPCC category Agriculture: (IPCC Level I Agriculture) Cement: Clinker production Waste: (IPCC Level I Waste) Petroleum Refining: (IPCC Level I Energy/IPCC Level II Fugitive/Sector: Petroleum Refining) Industrial: (IPCC Level I Industrial) minus Cement Oil & gas Extraction: (IPCC Level I Energy/IPCC Level II Fugitive/Sector: Oil Extraction) Electricity Fugitive Emissions: (IPCC Level I Energy/IPCC Level II Fugitive/Sector: Anything related to electricity generation including CHP) Pipeline Fugitive Emissions: (IPCC Level I Energy/IPCC Level II Fugitive/Sector: Pipelines Natural Gas)
Mitigation measure potential and costs	Short Lived Climate Pollutant Strategy and direct correspondence with California Air Resources Board staff. We exclude in-state transfers due to LCFS credits and avoid double-counting fuel savings benefits of energy efficiency from more efficient appliances.
Land use/ land change	Not currently modeled.