2020 Total System Electric Generation

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2019 Total System Electric Generation and previous years

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Fuel Type	California In-State Generation (GWh)	Percent of California In-State Generation	Northwest Imports (GWh)	Southwest Imports (GWh)	Total Imports (GWh)	Percent of Imports	Total California Energy Mix (GWh)	Total Californ Power Mix
Coal	317	0.17%	194	6,963	7,157	8.76%	7,474	2.74%
Natural Gas	92,298	48.35%	70	8,654	8,724	10.68%	101,022	37.06%
Oil	30	0.02%	-	-	0	0.00%	30	0.01%
Other (Waste Heat / Petroleum Coke)	384	0.20%	125	9	134	0.16%	518	0.19%
Nuclear	16,280	8.53%	672	8,481	9,154	11.21%	25,434	9.33%
Large Hydro	17,938	9.40%	14,078	1,259	15,337	18.78%	33,275	12.21%
Unspecified	-	0.00%	12,870	1,745	14,615	17.90%	14,615	5.36%

Fuel Type	California In-State Generation (GWh)	Percent of California In-State Generation	Northwest Imports (GWh)	Southwest Imports (GWh)	Total Imports (GWh)	Percent of Imports	Total California Energy Mix (GWh)	Total Californ Power Mix
Total Non-Renewables and Unspecified Energy	127,248	66.65%	28,009	27,111	55,120	67.50%	182,368	66.91%
Biomass	5,680	2.97%	975	25	1,000	1.22%	6,679	2.45%
Geothermal	11,345	5.94%	166	1,825	1,991	2.44%	13,336	4.89%
Small Hydro	3,476	1.82%	320	2	322	0.39%	3,798	1.39%
Solar	29,456	15.43%	284	6,312	6,596	8.08%	36,052	13.23%
Wind	13,708	7.18%	11,438	5,197	16,635	20.37%	30,343	11.13%
Total Renewables	63,665	33.35%	13,184	13,359	26,543	32.50%	90,208	33.09%
Total System Energy	190,913	100.00%	41,193	40,471	81,663	100.00%	272,576	100.00%

Total System Electric Generation and Methodology

Total system electric generation is the sum of all utility-scale, in-state generation, plus net electricity imports. Items of note for 2020:

- Total generation for California was 272,576 gigawatt-hours (GWh), down 2 percent, or 5,356 GWh, from 2019.
- California's non-CO2 emitting electric generation categories (nuclear, large hydroelectric, and renewables) accounted for 51 percent of its in-state generation, compared to 57 percent in 2019. The change is directly attributable to the significantly reduced hydroelectric generation, some 44 percent lower than 2019 generation levels, as dry conditions returned to the state.
- Net imports increased by about 6 percent (4,435 GWh) in 2020 to 81,663 GWh, partially offsetting the decreased output from California’s hydroelectric power plants.
- Total renewable energy reached 33 percent, 90,2080 GWh in 2020, up 2.5 percent from 2019 levels.

Overall, California's total grid-served electric generation continues to decline as local, distributed generation systems expanded across the state. Behind-the-meter residential rooftop solar photovoltaic systems directly reduce the measured delivery of power from the state's fleet of utility-scale power plants.[1]

In 2020, California experienced the third driest year since year since 1895, as drought conditions returned to the state. Similarly, 2020 had the third highest annual average temperature recorded over the past 126-year record. As a result, annual hydroelectric generation fell by 44 percent from 2019 levels to 21,414 GWh. As shown in **Figures 1** and **2**, total monthly hydroelectric generation in 2020 neared the lowest historical monthly levels of the past 19 years of CEC generation data.

As detailed in **Table 1** below, California's natural gas-fired electric generation increased by 7 percent in 2020 to 92,298 GWh, accounting for 48 percent of in-state generation. In-state renewables (small hydro, geothermal, biomass, solar, and wind) decreased by 1.4 percent compared to 2019, due to decreased generation from biomass (plant retirements) and small hydroelectric generation (drought conditions); combined wind and solar generation were up by 2 percent over 2019 levels while geothermal generation was up 3.4 percent in 2020.

Looking ahead into 2021, hydroelectric generation continues into historically low levels for each of the first five months of the year for which there is available CAISO data, as shown in **Figure 3**. Please note, the CAISO dataset does not include hydroelectric facilities from other balancing areas such as those within LADWP and BANC (SMUD), unlike **Figures 1** and **2**.

Figure 1: Comparison of 2020 Hydroelectric Generation to Historical Highs and Lows

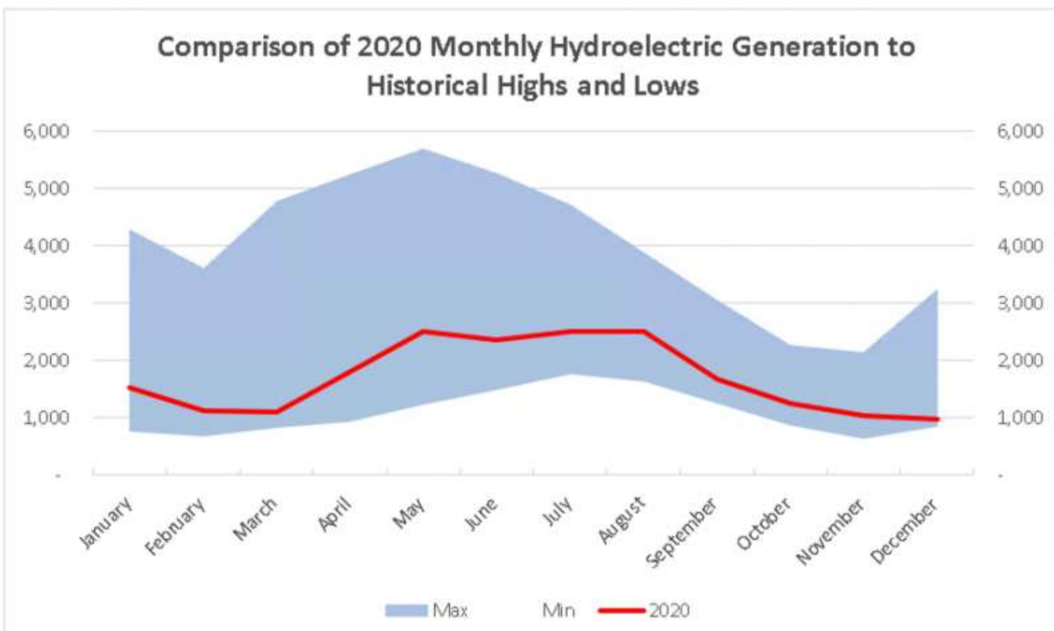

Figure 2: Monthly Hydroelectric Generation, January 2001 – December 2020

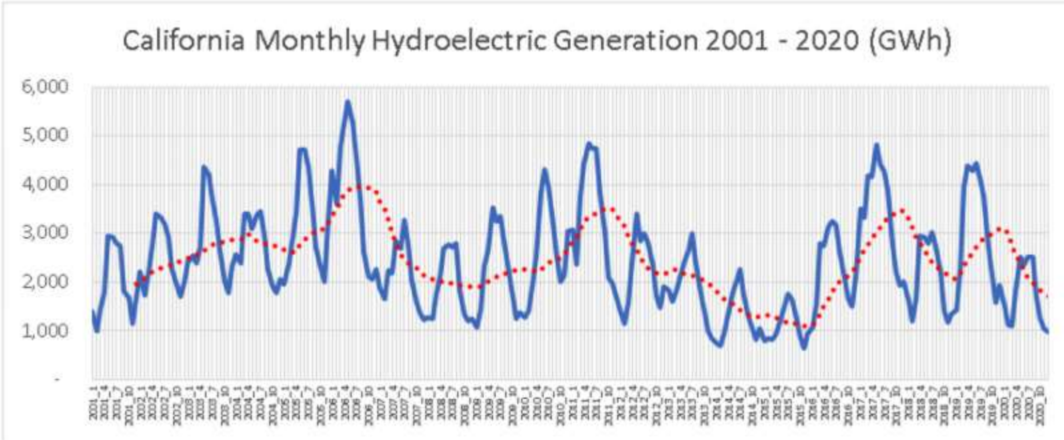

Figure 3: CAISO Monthly Hydroelectric Generation, January 2021 – May 2021

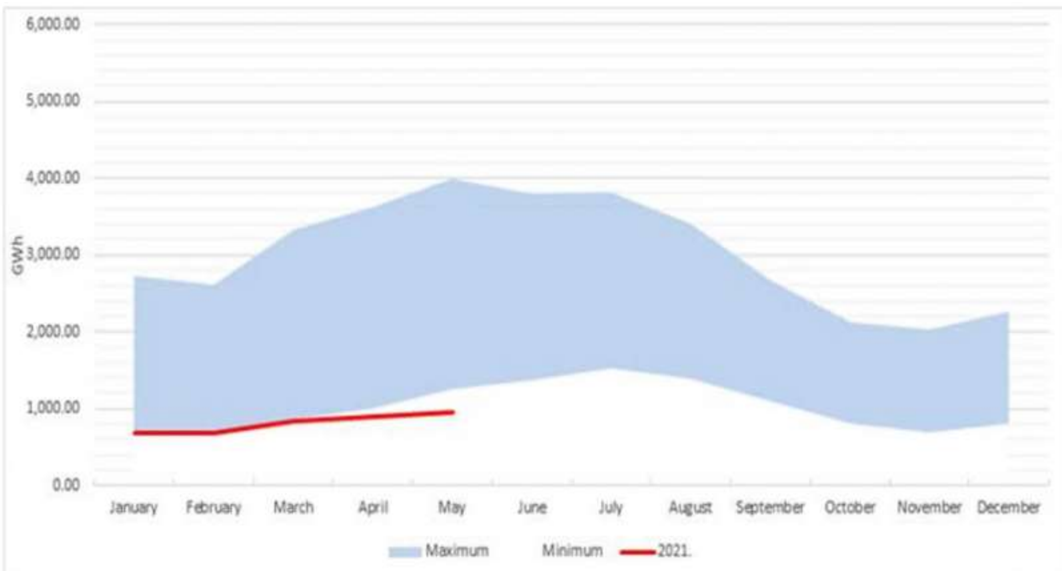

Table 1 – California Electric Generation and Net Imports, 2016-2020

	2016 GWh	2017 GWh	2018 GWh	2019 GWh	2020 GWh
Total System Electric Generation	290,792	292,083	285,656	277,933	272,576
Total In-State Generation	198,466	206,379	195,008	200,704	190,913
CA Hydroelectric	28,986	43,304	26,344	38,494	21,414
CA Large Hydro	*24,410*	*36,920*	*22,096*	*33,145*	*17,938*
CA Small Hydro	*4,576*	*6,384*	*4,248*	*5,349*	*3,476*
CA Nuclear	18,931	17,925	18,268	16,163	16,280
CA Coal	324	302	294	250	317
CA Oil	37	33	35	36	30

	2016 GWh	2017 GWh	2018 GWh	2019 GWh	2020 GWh
CA Natural Gas	98,879	89,588	90,691	86,134	92,298
CA Geothermal	11,582	11,745	11,528	10,967	11,345
CA Biomass	5,905	5,847	5,909	5,936	5,680
CA Wind	13,499	12,867	14,244	13,688	13,708
CA Solar PV	17,385	21,895	24,721	26,323	27,179
CA Solar Thermal	2,548	2,464	2,545	2,303	2,277
CA Petroleum Coke	207	246	207	191	197
CA Waste Heat	182	163	223	220	187
Net Imports	92,326	85,704	90,648	77,229	81,663

California Electrical Energy Generation

The California Code of Regulations (Title 20, Division 2, Chapter 2, Section 1304 (a)(1)-(2)) requires owners of power plants that are 1 MW or larger in California or within a control area with end users inside California to file data on electric generation, fuel use, and environmental attributes. Reports are submitted to the Energy Commission on a quarterly and annual basis. These reports cover all forms of electric generation including renewables, hydroelectric, natural gas, and others. The reporting requirement includes electricity from facilities that generate for onsite usage such as refineries and university campuses. Additionally, loads from hydroelectric facilities that are equipped with reversible turbines (a combined pump and turbine generator) are taken into account. Pumping-generating facilities use electricity to meet water storage, water transfer, and water delivery requirements, while pumped storage facilities use electricity to transfer water from one reservoir to another, usually during off-peak hours at night, so that electricity can be generated during the next day to help peak electricity demand. Energy Commission staff collect and verify these reports to compile a statewide accounting of all electric generation serving California.

Quarterly data reports submitted by balancing authorities for energy imports and exports are used to determine the net energy imports for California. Imports are tracked for two geographical regions: the Northwest and the Southwest. The allocation of fuel types is based on Power Source Disclosure reports from LSEs such as investor-owned utilities, publicly owned utilities, and community-choice aggregators.

What is Unspecified Power?

Unspecified power refers to electricity that is not traceable to a specific generating facility, such as electricity traded through open market transactions. Unspecified sources of power are typically a mix of resource types, and may include renewables. This category can also include spot market purchases, wholesale energy purchases, and purchases from pools of electricity where the original source of fuel can no longer be determined. As mentioned, it can also include renewable energy from a certified renewable facility that has been sold separately from its renewable attributes, or RECs. Renewable energy without its corresponding RECs is sometimes referred to as “null energy.”

Definitions

California Energy Mix: Total in-state electric generation plus Northwest and Southwest energy imports

California Power Mix: Percentage of specified fuel types derived from the California Energy Mix for use on the annual Power Content Label

In-State Generation: Energy from power plants physically located in the state of California

Northwest Imports: Energy imports from Alberta, British Columbia, Idaho, Montana, Oregon,South Dakota, Washington, and Wyoming

Southwest Imports: Energy imports from Arizona, Baja California, Colorado, Mexico, Nevada,New Mexico, Texas, and Utah

Total System Electric Generation: Used interchangeably with California Energy Mix

Total System Power: Original terminology used to describe California's annual electric generation.

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[1] Note, data reporting requirements for total system electric generation are limited to those facilities with a nameplate capacity of 1 MW and larger. As most solar PV systems installed on residential homes and commercial buildings are less than 1 MW, they are typically considered to be distributed generation and not required to report to the CEC.

Battery Storage in the United States: An Update on Market Trends

July 2020

List of Acronyms

AEO	*Annual Energy Outlook*
AK/HI	Alaska and Hawaii
CAES	Compressed-Air Energy Storage
CAISO	California Independent System Operator
CPUC	California Public Utility Commission
CSP	Concentrated Solar Power
DOE	U.S. Department of Energy
EIA	U.S. Energy Information Administration
ERCOT	Electric Reliability Council of Texas
FERC	Federal Energy Regulatory Commission
GW	Gigawatt
IOU	Investor-owned utilities
ITC	Investment tax credit
IPP	Independent power producer
IRP	Integrated resource plan
ISO-NE	Independent System Operator of New England
kW	Kilowatt
kWh	Kilowatthour
LADWP	Los Angeles Department of Water and Power
MISO	Mid-Continent Independent System Operator
MW	Megawatt
MWh	Megawatthour
PGE	Pacific Gas and Electric
PJM	PJM Interconnection
PPA	Power purchase agreement
SCE	Southern California Edison
SDGE	San Diego Gas and Electric
SGIP	Self-Generation Incentive Program
SMUD	Sacramento Municipal Utility District

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Executive Summary

Large-scale battery storage systems are increasingly being used across the power grid in the United States. In 2010, 7 battery storage systems accounted for only 59 megawatts (MW) of power capacity, the maximum amount of power output a battery can provide in any instant, in the United States. By 2015, 49 systems accounted for 351 MW of power capacity. This growth continued at an increased rate for the next three years, and the total number of operational battery storage systems has more than doubled to 125 for a total of 869 MW of installed power capacity as of the end of 2018.

This report explores trends in battery storage capacity additions in the United States and describes the state of the market as of 2018, including information on applications, cost, ongoing trends, and market and policy drivers. These observations consider both power capacity and energy capacity, the total amount of energy that can be stored by a battery system. Some key observations are as follows:

At the end of 2018, 869 megawatts (MW) of power capacity,[1] representing 1,236 megawatthours (MWh) of energy capacity,[2] of large-scale[3] battery storage was in operation in the United States.

- Over 90% of large-scale battery storage power capacity in the United States was provided by batteries based on lithium-ion chemistries.
- About 73% of large-scale battery storage power capacity in the Unites States, representing 70% of energy capacity, was installed in states covered by independent system operators (ISOs) or regional transmission organizations (RTOs).
- Alaska and Hawaii, with comparatively smaller electrical systems that account for 1% of total grid capacity in the United States, accounted for 12% of the power capacity in 2018, or 14% of large-scale battery energy capacity.
- Historically, the majority of annual battery installations have occurred within the PJM Interconnection (PJM), which manages energy and capacity markets and the transmission grid in 13 eastern and Midwestern states and the District of Columbia, and California Independent System Operator (CAISO) territories. However, in 2018, over 58% (130 MW) of power capacity additions, representing 69% (337 MWh) of energy capacity additions, were installed in states outside of those areas.

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[1] As the maximum instantaneous amount of power output, power capacity is measured in units such as megawatts (MW)

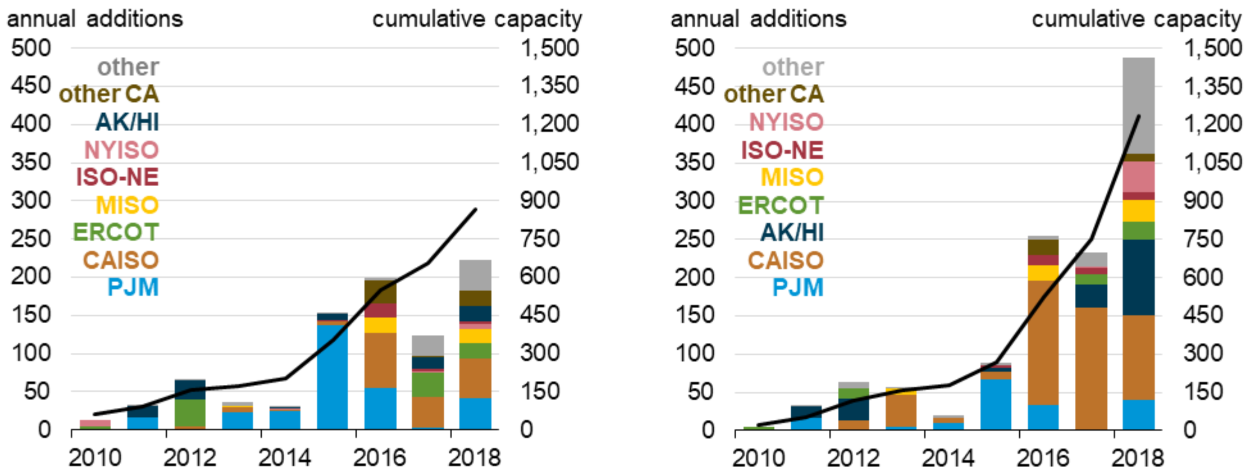
[2] As the total amount of energy that can be stored or discharged by a battery storage system, energy capacity is measured in megawatt-hours (MWh)

[3] Large-scale refers to systems that are grid connected and have a nameplate power capacity greater than 1 MW.

Figure ES1. Large-scale battery storage capacity by region (2010–2018)

power capacity **energy capacity**

megawatts megawatthours



Sources: U.S. Energy Information Administration, Form EIA-860M, *Preliminary Monthly Electric Generator Inventory*; U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*

Approximately one third (32%) of large-scale battery storage power capacity (and 14% of energy capacity) in the United States in 2018 was installed in PJM.

- In 2012, PJM created a new frequency regulation market product for fast-responding resources, the conditions of which were favorable for battery storage. However, changes implemented in 2017 in PJM's market rules have reduced the number of battery installations in the region.
- Most existing large-scale battery storage power capacity in PJM is owned by independent power producers (IPPs) providing power-oriented frequency regulation services.

Installations in CAISO accounted for 21% of existing large-scale battery storage power capacity in the United States in 2018, but they accounted for 41% of existing energy capacity.

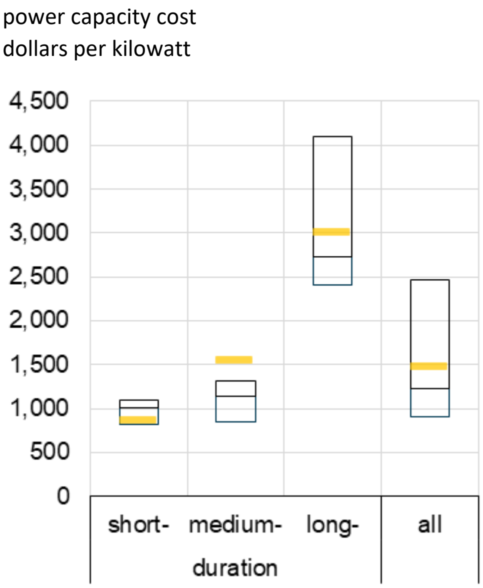
- In 2013, the California Public Utility Commission (CPUC) implemented Assembly Bill 2514 by mandating that the state's investor-owned utilities procure 1,325 MW of energy storage by 2020.
- Large-scale installations in California tend to provide energy-oriented services and tend to serve a wider array of applications than systems in PJM.
- Four California utilities held nearly 90% of small-scale[4] storage power capacity in the United States in 2018.

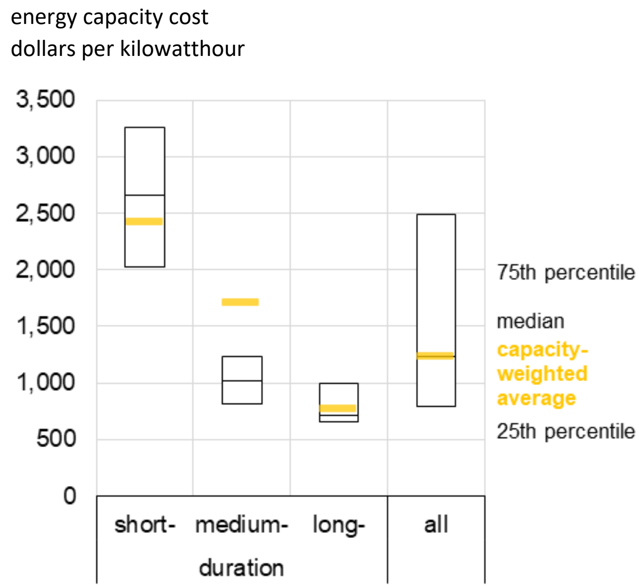
[4] Small-scale refers to systems connected to the distribution network and have a nameplate power capacity less than 1 MW.

Battery storage costs have been driven by technical characteristics such as the power and energy capacity of a system.

- On a per-unit of power capacity basis, total installed system costs for batteries of shorter duration have been less expensive than long-duration systems (Figure ES2).
- In terms of costs per-unit of energy capacity, the reverse has been true—longer duration batteries have typically had lower normalized costs compared with shorter-duration batteries (Figure ES2).
- Over time, average costs per-unit of energy capacity have decreased by 61% between 2015 and 2017, from $2,153/kWh to $834/kWh (Figure ES3).

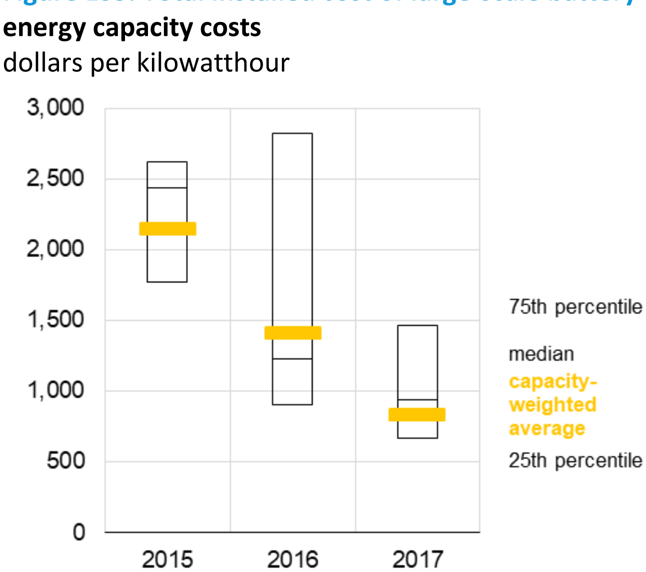
Figure ES2. Total installed cost of large-scale battery storage systems by duration (2013 -2017)





Source: U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*

Figure ES3. Total installed cost of large-scale battery storage systems by year



Source: U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*

Introduction

This report examines trends in the installation of batteries for large-scale electricity storage in the United States by describing the current state of the market, including information on applications, costs, and market and policy drivers.

This report focuses on battery storage technologies, although other energy storage technologies are addressed in the appendix. Electrical, thermal, mechanical, and electrochemical technologies can be used to store energy.

The capacity of battery storage is measured in two ways: *power capacity* and *energy capacity*. Generation is often characterized in terms of power capacity, which is the maximum amount of power output possible in any instant, measured in this report as megawatts (MW). However, batteries can sustain power output for only so long before they need to recharge. The *duration* of a battery is the length of time that a storage system can sustain power output at its maximum discharge rate, typically expressed in hours. The energy capacity of the battery storage system is defined as the total amount of energy that can be stored or discharged by the battery storage system, and is measured in this report as megawatthours (MWh).

Hydroelectric pumped storage, a form of mechanical energy storage, accounts for most (97%) large-scale energy storage power capacity in the United States. However, installation of new large-scale energy storage facilities since 2003 have been almost exclusively electrochemical, or battery storage.

This report explores trends in both large-scale and small-scale battery storage systems. EIA defines large-scale (or utility-scale) systems as being connected directly to the electricity grid and having a nameplate power capacity (the maximum rated output of a generator, usually indicated on a nameplate physically attached to the generator) greater than 1 MW. Small-scale refers to systems that have less than 1 MW in power capacity. Such systems are typically connected to a distribution network, the portion of the electrical system that delivers electricity to end-users.[5]

[5] Large-scale and small-scale reporting conventions are derived from the reporting requirements of the EIA *Electric Generators Report* (Form EIA-860) survey and the EIA *Electric Power Industry Report* (Form EIA-861) survey. The reporting cut-offs for these surveys are based entirely on the power capacity of the generator.

Large-Scale Battery Storage Trends

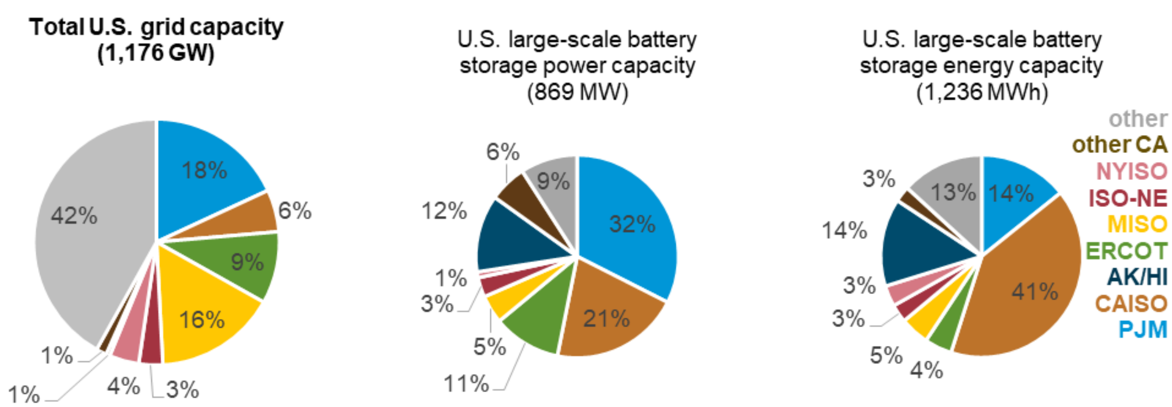
The first large-scale[6] battery storage installation recorded by EIA in the United States that was still in operation in 2018 entered service in 2003. Only 59 MW of power capacity from large-scale battery storage systems were installed between 2003 and 2010. However, this sector has experienced growth in recent years. Between 2011 and 2018 there were 810 MW of power capacity from large-scale battery storage added leaving a total of 869 MW battery storage power capacity operational by the end of 2018.

Most of existing U.S. power capacity has been installed by independent power producers in the PJM Interconnection (PJM), which coordinates the movement of electricity through all or parts of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia and the District of Columbia. Regulated utilities in the California Independent System Operator (CAISO) territory have procured significant amounts of storage capacity as well. The United States observed a new record for annual power capacity additions in 2018 when it saw 222 MW of large-scale battery storage installed, breaking the previous record of 199 MW added in 2016.

Regional Trends

As shown in Figure 1, about 73% of large-scale battery storage power capacity and 70% of energy capacity in the United States is installed in areas covered by independent system operators (ISOs) or regional transmission organizations (RTOs)[7]. The ISOs and RTOs, depicted in Figure 2, account for 58% of total grid capacity in the United States and have the largest shares of storage capacity relative to their shares of installed grid capacity. The disproportionate share of large-scale battery storage across the ISOs and RTOs may result from differences in market design and state policies (See Market and Policy Drivers section).

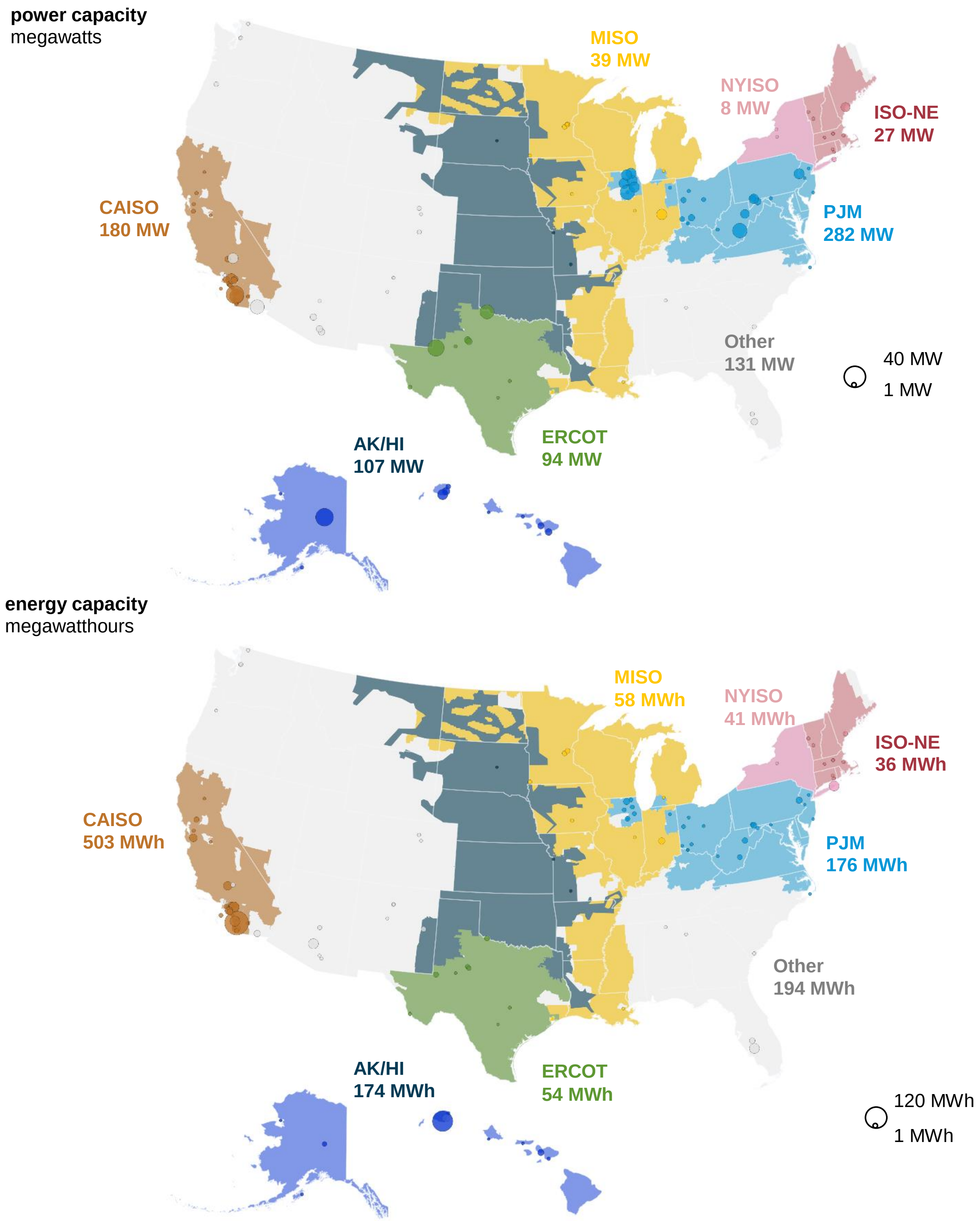
Figure 1. Large-scale power and energy capacity by region (2018)



Sources: U.S. Energy Information Administration, Form EIA-860M, *Preliminary Monthly Electric Generator Inventory*; U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*

[6] Large-scale refers to systems that are grid connected and have a nameplate power capacity greater than 1 MW.
[7] ISOs and RTOs are independent, federally regulated non-profit organizations that ensure reliability and optimize supply and demand bids for wholesale electric power.

Figure 2 Large-scale battery storage installations by region (2018)



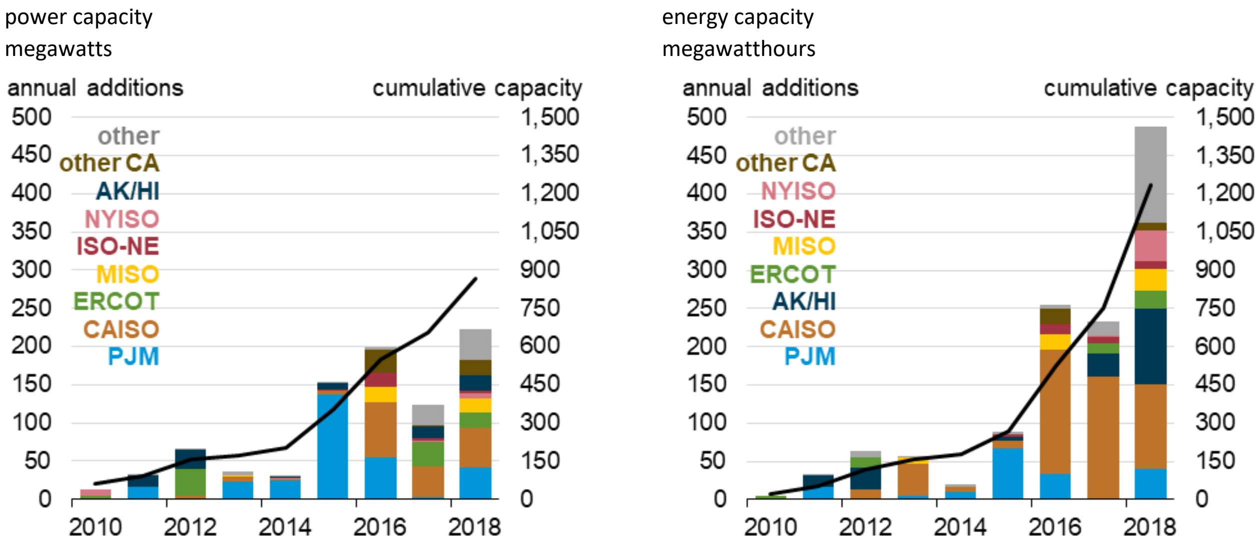
Sources: U.S. Energy Information Administration, Form EIA-860M, *Preliminary Monthly Electric Generator Inventory*; U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*

Notes: Energy capacity data for large-scale battery storage installed in 2018 are based on preliminary estimates.

Between 2003 and 2018, 922 MW of large-scale battery storage power capacity across 134 systems was installed in the United States, three-quarters of which was installed between 2015 and 2018. More than 30% of existing large-scale battery storage power capacity as of 2018 was located in the PJM Interconnection (Figure 2), most of which was built from 2014-2016. This was most likely the result of changes in PJM's market for frequency regulation (a grid service that helps balance momentary differences between electricity demand and supply within the transmission grid) in 2012 which created a specific requirement for fast response resources, such as batteries. In 2015, PJM put a cap on the market share for fast responding resources due to grid reliability concerns,[8] and PJM has had relatively flat storage growth since these changes were implemented.

Installations in PJM tend to be power-oriented with larger capacities but shorter durations to serve frequency regulation applications. In 2018, large-scale battery storage installations in PJM had an average power capacity of 10.8 MW and an average duration of 45 minutes. This matches the average duration that was observed in 2017 for PJM.

Figure 3. Large-scale battery storage capacity by region (2003–2018)



Sources: U.S. Energy Information Administration, Form EIA-860M, *Preliminary Monthly Electric Generator Inventory*; U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*

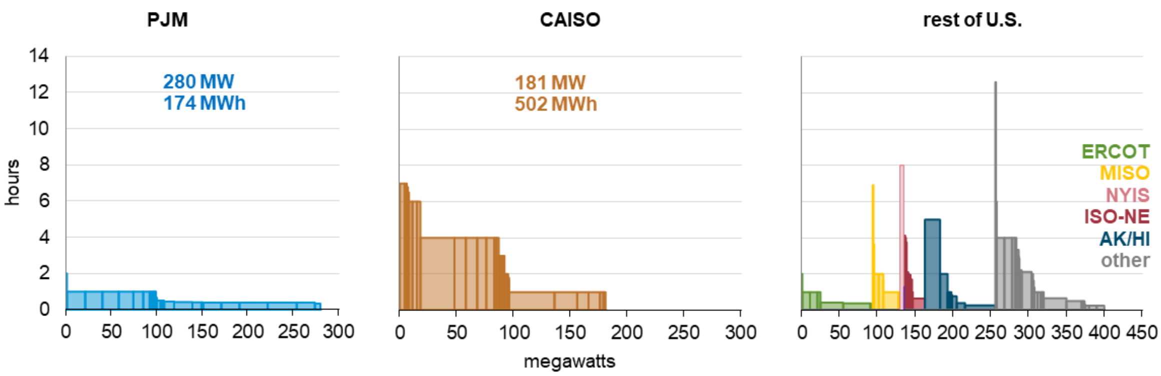
Although installations in CAISO accounted for 21% of existing large-scale battery storage power capacity in the United States in 2018, they accounted for 41% of existing energy capacity (Figure 3). California's need for battery storage has been for reliability purposes, so large-scale battery storage installations tend to be energy-oriented with small power capacities but long durations.

In 2018, large-scale battery storage installations in CAISO had an average power capacity of 6 MW and duration of 3.5 hours (Figure 4). This is longer than the average duration of 3.2 hours in CAISO in 2017. Other markets in the United States show a mix of power- and energy-oriented battery installations.

[8] FERC Docket No. ER19-1651-000, PJM Interconnection ORDER ON CONTESTED SETTLEMENT, https://elibrary.ferc.gov/idmws/file_list.asp?document_id=14845834

Of the power capacity in California, 37% was procured by Southern California Edison and San Diego Gas and Electric to address reliability risks as a result of constraints on the natural gas supply following a leak at Aliso Canyon, a major natural gas storage facility in the region. The California Public Utilities Commission (CPUC) requires generation resources to provide at least four hours of output to contribute to reliability reserves. As a result, large-scale battery storage installations in California tend to need larger energy capacities to qualify as reliability resources. (See Market and Policy Drivers for more information on California's activities related to energy storage.)

Figure 4. Power capacity and duration of large-scale battery storage by region (2018)

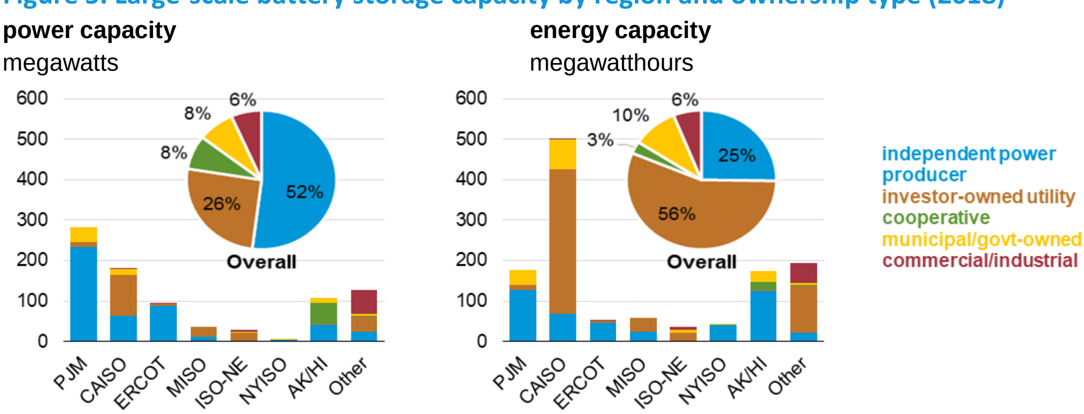


Source: U.S. Energy Information Administration, Form EIA-860M, *Preliminary Monthly Electric Generator Inventory*; U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*
Note: Energy capacity data for large-scale battery storage installed in 2018 are based on preliminary estimates. Duration is calculated by dividing nameplate energy capacity (in megawatthours [MWh]) by maximum discharge rate (in megawatts [MW]), except in cases where the maximum discharge rate was not available, in which case the nameplate rating was used instead.

Ownership Trends

At the end of 2018, slightly more than half (52%) of the existing power capacity of large-scale battery storage in the United States was owned by independent power producers (IPPs) while more than half (56%) of large-scale battery storage in terms of energy capacity was owned by investor-owned utilities (IOUs) (Figure 5). This ownership structure reflects the dominance of IPPs in PJM with its power-oriented storage applications and the IOU ownership of energy-oriented reliability assets in CAISO.

Figure 5. Large-scale battery storage capacity by region and ownership type (2018)



Source: U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*

Although there are relatively fewer large-scale battery storage installations outside of PJM and CAISO, some noteworthy points emerge in other regions. Most (94%) of the installations in the Electric Reliability Council of Texas (ERCOT), which is regulated by the Public Utility Commission of Texas, are owned by IPPs. Of the eight installations in Mid-Continent Independent System Operator (MISO), six are owned by IOUs. In Alaska, most large-scale battery storage energy capacity is owned by IPPs, while the power capacity is split between cooperatives and IPPs. State-owned utilities in the U.S. own 8% of large-scale battery storage power capacity, driven by a single large (30 MW/20 MWh) installation in southern California owned by the Imperial Irrigation District.

Chemistry Trends

Chemistry Descriptions

Battery storage technologies make use of several different battery chemistries. The most common that have seen large-scale deployment[9,10,11] in the United States include:

- **Lithium-ion** technology, which represented more than 90% of the installed power and energy capacity of large-scale battery storage in operation in the United States at the end of 2018. Lithium-ion batteries have high-cycle efficiency (they don't lose much energy between recharge and discharge) and fast response times. In addition, their high energy density (stored energy per unit of weight) makes them the current battery of choice for most portable electronic and electric vehicle applications.
- **Nickel-based** batteries were used in some of the earliest large-scale battery storage installations in the United States, including a 2003 system added in Fairbanks, Alaska. Since then, the deployment of this battery chemistry has been limited. Nickel-based batteries typically have high energy density and reliability but relatively low cycle life (fewer recharge/discharge cycles before degrading performance beyond specifications for the application).
- **Sodium-based** battery storage accounted for 2% of the installed large-scale power capacity and 6% of the installed large-scale energy capacity in the United States at the end of 2018. Sodium based battery storage is an established technology based on abundant materials with a long cycle life suitable for long-discharge applications. These systems require high operating temperatures as they utilize molten sodium to operate (~300°C).
- **Lead acid** is one of the oldest forms of battery storage; its development began in the mid-1800s. Lead acid is widely used as a starter battery in vehicles. Lead acid covered only 1% of large-scale battery storage capacity installed at the end of 2018 in the United States and has seen limited grid-scale deployment because of its relatively low energy density and cycle life.
- **Flow battery** systems have one or more chemical components that are dissolved in a liquid solution. The chemical solutions are typically stored in tanks and separated by a membrane. The overall battery capacity is determined by tank size and can be expanded to meet different applications. They have a long cycle life, and their operational lifetime is projected to be long. At the end of 2018, flow batteries represented less than 1% of the installed power and energy capacity of large-scale battery storage in the United States.

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[9] Akhil, Abbas A., et al. *DOE/EPRI Electricity Storage Handbook in Collaboration with NRECA*. January 2015. http://www.sandia.gov/ess/publications/SAND2015-1002.pdf

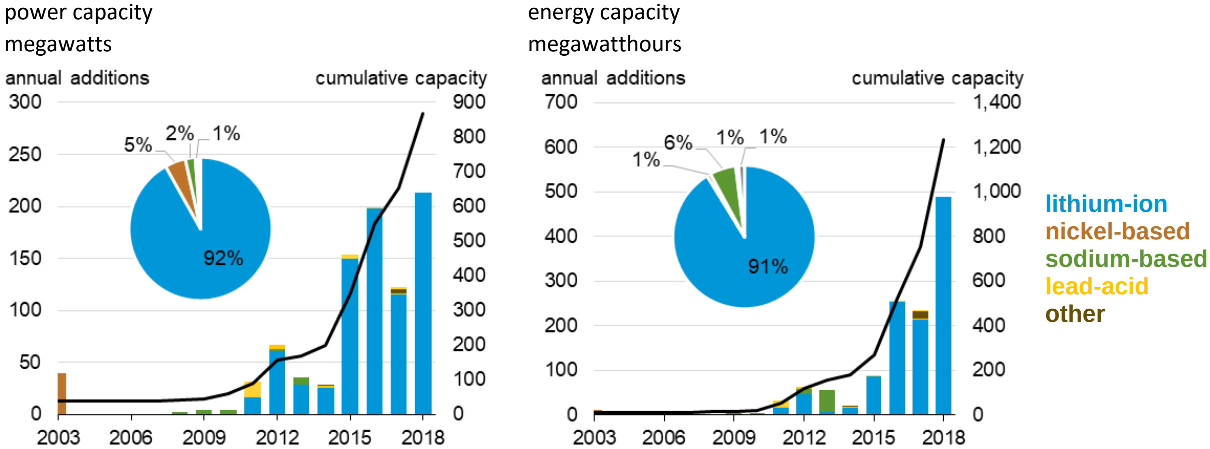
[10] Chen, Haisheng, et al. *Progress in electrical energy storage system: A critical review*. Progress in Natural Science, March 2009.

[11] Luo, Xing, et al. Overview of current development in electrical energy storage technologies and the application potential in power system operation. Applied Energy, January 2015

Chemistry Trends

The earliest large-scale battery storage installations in the United States used nickel-based and sodium-based chemistries (Figure 6). However, since 2011, most installations have opted for lithium-ion batteries, including retrofits of older systems that initially relied on different chemistries. For example, in 2012, Duke Energy added 36 MW of lead-acid battery storage to its Notrees wind power facility in West Texas. When the lead-acid batteries were first installed, the battery system participated in the region's frequency regulation market, which required rapid charging and discharging that significantly degraded the batteries. In 2016, Duke Energy replaced the original lead-acid batteries with better performing lithium-ion batteries.[12]

Figure 6. Large-scale battery storage capacity by chemistry (2003–2018)



Source: U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*

Flow batteries are an emerging energy storage technology. The first large-scale flow battery storage system in the United States was installed in Washington in 2016 by Avista Utilities. Two more flow batteries were installed in 2017 by electric utilities in Washington and California. The vanadium based electrolyte used in these flow battery systems is stored in large tanks and pumped through a separately connected electrode system. This configuration allows for greater energy capacities at lower prices, but it lowers the round trip efficiency[13] of the stored electricity as a result of the operation of the pumps.[14] Other battery storage chemistries and technologies are in different phases of development but have yet to see significant deployment in large-scale grid applications in the United States.

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[12] Duke Energy, *Duke Energy to upgrade its Notrees Energy Storage System*, June 2015, https://news.duke-energy.com/releases/duke-energy-to-upgrade-its-notrees-energy-storage-system

[13] Round-trip efficiency is the battery system efficiency over one cycle, measured as the amount of energy discharged to a specified depth over the amount of energy consumed to bring the system back up to its specified initial state of charge.

[14] Amerseco, Inc., *Demonstrating the Benefits of Long-Duration, Low-Cost Flow Battery Storage in a Renewable Microgrid*, December 2019, https://www.serdp-estcp.org/Program-Areas/Installation-Energy-and-Water/Energy/Microgrids-and-Storage/EW19-5312

Current Applications

Batteries have both physical and operational constraints, such as power output and discharge duration. These constraints affect individual battery technology choices that are often made with the intent of optimizing the delivery of certain types of services or providing specific applications to the electricity grid. In some cases it is also possible or even necessary to combine applications to maximize the value of the system. For a more complete discussion, please refer to the reference work cited below.

Application Descriptions

The leading types of existing battery applications[15] include the following:

- **Frequency regulation** helps balance momentary differences between electricity demand and supply within the transmission grid, often in order to help maintain interconnection frequencies close to 60 Hertz.
- **Spinning reserve** is the unused dispatchable generating capacity of online assets that provides grid frequency management, which may be available to use during a significant frequency disturbance, such as during an unexpected loss of generation capacity. This reserve ensures system operation and availability. Dispatchable generators are those that can be turned on or off in order to meet immediate needs of the system.
- **Voltage or reactive power support** ensures the quality of power delivered by maintaining the local voltage within specified limits by serving as a source or sink of reactive power (the portion of electricity that establishes and sustains the electric and magnetic fields of alternating-current equipment).
- **Load following** supplies (discharges) or absorbs (charges) power to compensate for load variations—this application is a power balancing application, also known as a form of ramp rate control.
- **System peak shaving** reduces or defers the need to build new central generation capacity or purchase capacity in the wholesale electricity market, often during times of peak demand.
- **Arbitrage** occurs when batteries charge during periods when electrical energy is less expensive and discharge when prices for electricity are high, also referred to as electrical energy time-shift.
- **Load management** provides a demand side customer-related service, such as power quality, power reliability (grid-connected or microgrid operation), retail electrical energy time-shift, demand charge management, or renewable power consumption maximization (charging the battery storage system during periods when renewable energy is greatest so as to consume the maximum renewable energy from the battery system, i.e. charging with solar during the day or charging with wind during high wind periods).
- **Storing excess wind and solar generation** reduces the rate of change of the power output from a non-dispatchable generator in order to comply with local grid requirements related to grid stability or prevent over production or over-production penalties. Non-dispatchable generators cannot be turned on or off in order to meet immediate needs and are often intermittent resources (generators with output controlled by the natural variability of the energy source, for example wind and solar).

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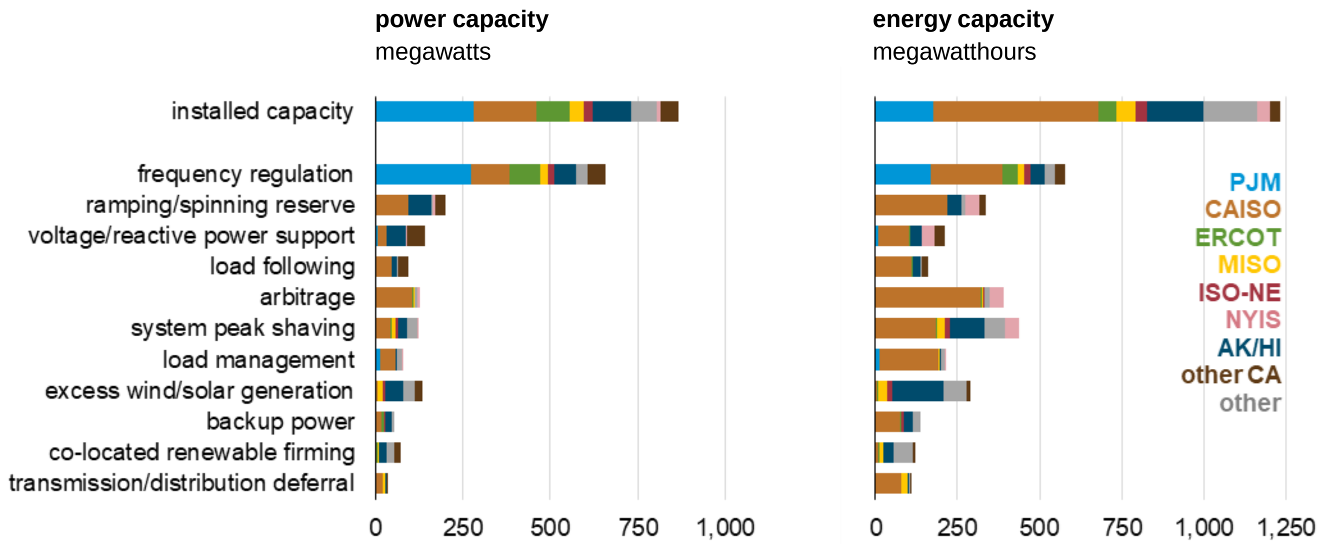
[15] DNV-GL, *Recommended Practices: Safety, operation and performance of grid-connected energy storage systems*, September 2017, https://rules.dnvgl.com/docs/pdf/DNVGL/RP/2017-09/DNVGL-RP-0043.pdf?_ga=2.80787476.2095102769.1516371272-888917498.1516371272

- **Backup power**, following a catastrophic failure of a grid, provides an active reserve of power and energy that can be used to energize transmission and distribution lines, provides start-up power for generators, or provides a reference frequency.
- **Transmission and distribution deferral** keeps the loading of the transmission or distribution system equipment below a specified maximum. This application allows for delays in transmission upgrades, avoids the need to upgrade a transmission system completely, or avoids congestion-related costs and charges.
- **Co-located generator firming** provides constant output power over a certain period of time of a combined generator and energy storage system. Often the generator in this case is a non-dispatchable renewable generator (for example, wind or solar).

Applications by Region

Figure 7 illustrates the total amount of power and energy capacity that was available for each application in the United States in 2018. In the United States, 75% of large-scale battery storage power capacity provides frequency regulation, which helps systems quickly balance unexpected differences in electricity supply and demand. Installations in PJM have driven this trend, where a specific market product for fast-ramping frequency regulation led independent power producers to rapidly deploy large-scale battery storage. Installations in CAISO as of 2018 tended to serve a wider array of applications than those in PJM because many had been procured by regulated utilities to serve multiple applications without necessarily being directly compensated for each application through market mechanisms.

Figure 7. Applications served by large-scale battery storage (2018)



Source: U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*

Figure 7 is based on information provided by EIA-860 survey respondents regarding their market region and the applications that battery storage systems provided in 2018. A survey respondent was permitted to select more than one application provided by each battery system.

EIA-860 survey respondents reported that storage in PJM was used for primarily only one application (frequency regulation), while batteries installed in CAISO were used for several (2.7 applications on average). Batteries installed in Alaska and Hawaii were diversely used (4.0 applications on average).

Battery Storage Costs

Costs for battery storage technologies depend on technical characteristics such as the power capacity and energy capacity of a system.

Cost Background

This discussion of costs is divided into three main categories based on the nameplate duration of the battery storage system, which is the ratio of nameplate energy capacity to nameplate power capacity.

- The short-duration battery storage category includes systems with less than 0.5 hours of nameplate duration.
- The medium-duration battery storage category includes systems with nameplate durations ranging between 0.5 hours and 2.0 hours.
- The long-duration battery storage category includes all systems with more than 2.0 hours of nameplate duration.

The average characteristics of the categorized sample data are summarized in Table 1. These categorizations are used in this report to illustrate the importance of defining the system characteristics when discussing costs, especially regarding power capacity versus energy capacity. The reported capital cost values are from large-scale battery storage systems installed across the United States between 2013 and 2017 and include multiple reported battery chemistries.

As shown in Table 1, for costs reported between 2013 and 2017, short-duration battery storage systems had an average power capacity of 11.7 MW, medium-duration systems had an average capacity of 7.2 MW, and long-duration battery storage systems had 6 MW. The average energy capacity for the short- and medium-duration battery storage systems were 4.2 and 6.6 MWh, respectively. The average for the long-duration battery storage systems was 23.5 MWh, between 4 and 6 times more than the average energy capacity of short and medium duration battery storage systems.

Table 1. Sample characteristics of capital cost estimates for large-scale battery storage by duration (2013 -2017)

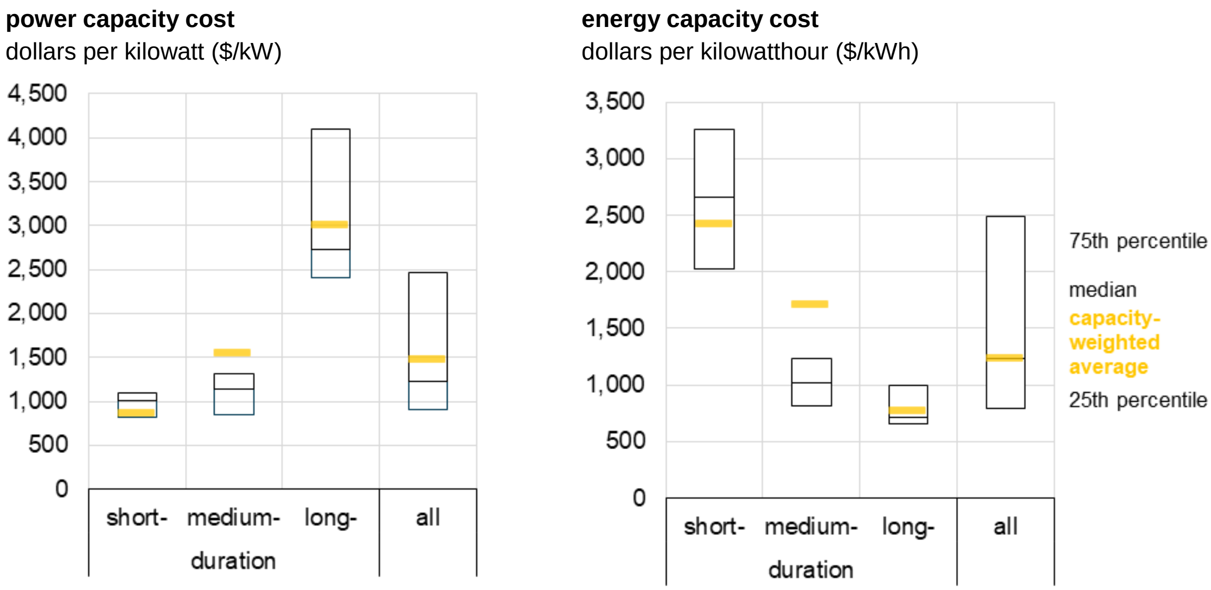
	Short-duration <0.5 hours	**Medium-duration** 0.5–2 hours	**Long-duration** >2 hours
Number of battery systems with reported costs available	22	20	16
Average of nameplate power capacity, megawatts (MW)	11.7	7.2	6.0
Average of nameplate energy capacity, megawatthours (MWh)	4.2	6.6	23.5
Average of nameplate duration, hours	0.4	1.1	4.2
Capacity-weighted cost per unit power capacity, dollars per kilowatts ($/kW)	864	1,554	3,006
Capacity-weighted cost per unit energy capacity, dollars per kilowatthour ($/kWh)	2,425	1,710	772

Source: U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*

Cost Results

Based on costs reported between 2013 and 2017, battery systems with shorter durations typically had lower normalized power capacity costs measured in dollars per kilowatt ($/kW) than batteries with longer nameplate durations (Figure 8). The opposite was generally true when examining normalized energy capacity costs measured in dollars per kilowatthour ($/kWh) because total system costs for longer-duration systems are spread out over more stored energy. Nonetheless, the range of normalized cost values was driven by technological and site-specific requirements.

Figure 8. Total installed cost of large-scale battery storage systems by duration (2013 -2017)



Source: U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*

Normalized energy capacity costs have decreased over time (Table 2, Figure 9). The capacity-weighted average installed cost of large-scale batteries fell by 34% from $2,153/kWh in 2015 to $1,417/kWh in 2016. This trend continued into 2017 with another decrease in average installed costs of 41% to $834/kWh. This trend ultimately resulted in a total 61% decrease in average installed costs between 2015 and 2017.

Table 2. Sample characteristics of capital cost estimates for large-scale battery storage by year

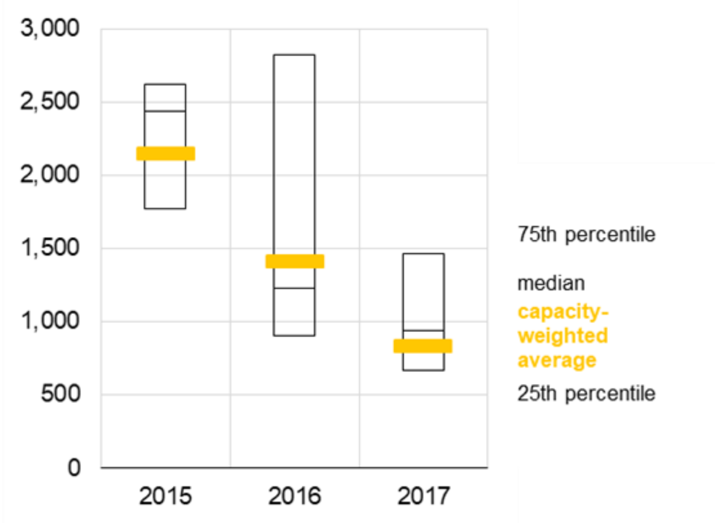
	2015	2016	2017
Number of battery systems with reported costs available	10	21	22
Average of nameplate power capacity, megawatts (MW)	12.7	10.4	5.6
Average of nameplate energy capacity, megawatthours (MWh)	5.4	12.2	10.6
Average of nameplate duration, hours	0.5	1.5	1.8
Capacity-weighted cost per unit power capacity, dollars per kilowatts ($/kW)	913	1,664	1,587
Capacity-weighted cost per unit energy capacity, dollars per kilowatthour ($/kWh)	2,153	1,417	834

Source: U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*

Figure 9. Total installed cost of large-scale battery storage systems by year

energy capacity costs

dollars per kilowatthour



Source: U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*

Note: Cost observations for installation years 2013 and 2014 were dropped from this figure as a result of small sample sizes for those respective years.

Unlike non-storage technologies, battery storage can supply and consume energy at different times of the day, creating a combination of cost and revenue streams that makes it challenging to directly compare to generation technologies. They are not stand-alone generation sources and must buy electricity supplied by other generators to recharge and cover the round-trip efficiency losses experienced during cycles of charging and discharging.

There are two major challenges in determining the profitability and cost of battery storage systems. First, quantifying the competitiveness of a battery storage technology with other technologies operating on the grid must consider the individual markets that the storage technology is planning to be used in and what revenue opportunities exist for the technology. The second challenge involves the degradation of the system over time, which is the lasting and continuous decrease in either a battery's power or energy performance or both and is linked to use or age of a battery component or system.

The performance can be characterized by the full cycle power input and output at an agreed-upon charge/discharge rate. There are two general options that can be employed to ensure reliable performance during a storage system's lifetime:

- **Overbuilding**: adding more storage or discharge capacity behind the inverter than is needed, so that as the system ages it will maintain a capacity at or above the contracted capacity required of the system.
- **Continual Upgrades**: replacing some portion of the storage system to maintain the agreed-upon performance during its lifetime.

The two approaches to meeting performance requirements affect the installed capital costs of the system. Overbuilding storage capacity leads to a higher initial installed capital cost, while continual upgrades lead to higher operation and maintenance costs throughout the lifetime of the storage facility. Therefore, comparing only the normalized capital cost of various battery systems, as shown in **Figure 8**, does not capture the variation in the lifetime costs. The costs collected and presented in this report are not sufficient to capture all of these nuances.

Other Cost Metrics

In addition to the capital costs presented in this section, EIA has observed trends in battery storage costs arising from the negotiated price of electricity for projects that are financed through power purchase agreements (PPAs). PPAs are contracts between electricity suppliers and electricity buyers (or offtakers) at a fixed price per unit of electricity delivered. They represent a predictable, long-term source of revenue to the project. The negotiated electricity prices under a PPA are heavily influenced by each project's specifications, contract terms, and other localized factors. Observing PPA prices can give an indication of cost trends over time; however, PPA prices are not comparable to total capital costs of the system.

Small-Scale Energy Storage Trends

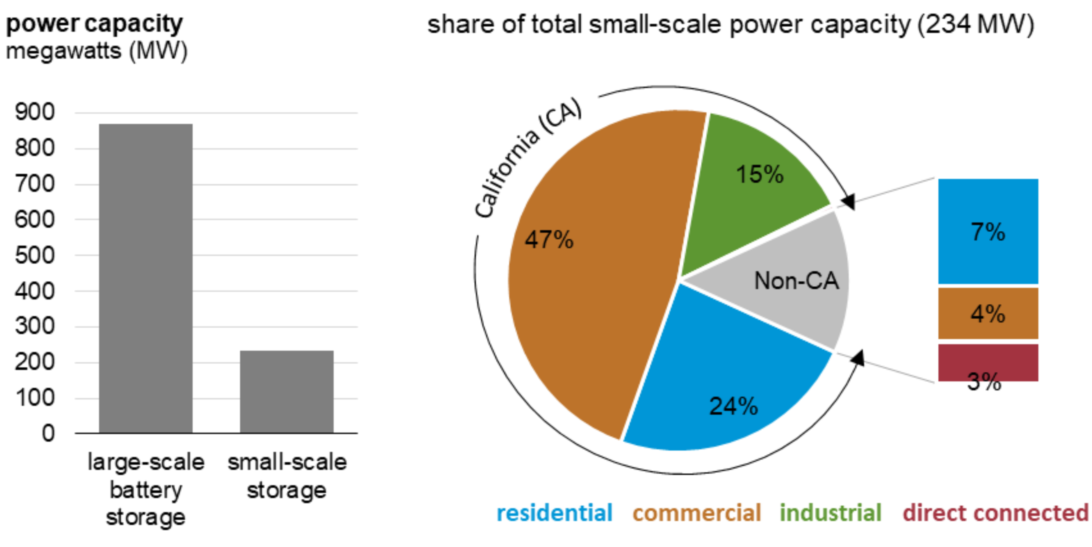
In 2018, utilities reported 234 MW of existing small-scale storage power capacity in the United States. A little more than 50% of this capacity was installed in the commercial sector, 31% was installed in the residential sector, and 15% was installed in the industrial sector. The remaining 3% was directly connected to the distribution grid, such as by the utility at their own distribution substation.

The data collected for small-scale applications depend on the electric utility's access to information about installations in its territory. If end users of storage systems are installing systems for purposes where the system would not interact with the distribution network—for example back-up applications—the electricity distribution utility may not know about those system installations. Utilities collect information on small-scale storage systems primarily through inter-connection agreements. Because these agreements are designed by the utilities, the information about storage units may not be collected in a consistent format across all utilities.

Small-Scale Energy Storage Trends in California

As shown in Figure 10, in 2018, 86% of reported small-scale storage power capacity in the United States was in California and, specifically, was owned by six utilities: Southern California Edison (SCE), Pacific Gas and Electric (PGE), San Diego Gas and Electric (SDGE), Los Angeles Department of Water and Power (LADWP), Sacramento Municipal Utility District (SMUD), and City of Moreno Valley. In 2018, most installations of small-scale storage in the commercial sector in California were in SCE's territory (64% of such capacity) and SDGE's territory (22%). Most installations (95%) of small-scale storage in the industrial sector in California were in PGE's territory.

Figure 10. Small-scale energy storage capacity by sector (2018)



Source: U.S. Energy Information Administration, Form EIA-861, *Annual Electric Power Industry Report*
Note: Data collected on small-scale storage may include forms of energy storage other than batteries. Direct-connected storage is not located at an ultimate customer's site but is in front of the meter or connected directly to a distribution system or both. Direct-connected storage in California and industrial storage outside of California are less than 1% of the total and are therefore not depicted in the figure.

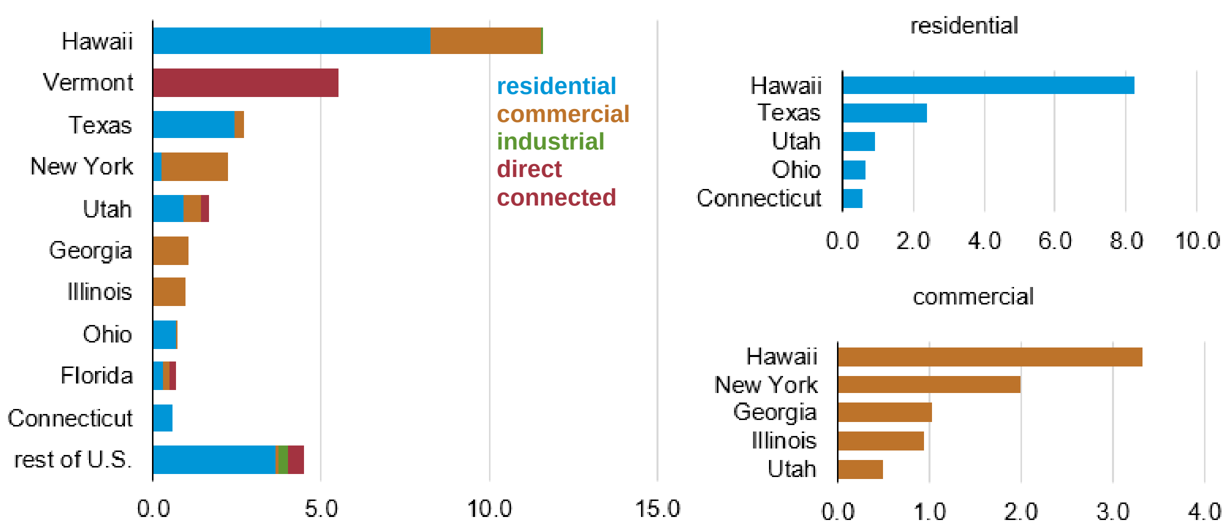
California's large share of small-scale energy storage power capacity can be attributed to the state's Self-Generation Incentive Program (SGIP), which provides financial incentives for installing customer-sited distributed generation. Installations receiving rebates through SGIP contribute to California's 2013 energy storage mandate (Assembly Bill 2514), which requires 200 MW of customer-sited energy storage to be installed by 2024. In May 2017, the California Public Utilities Commission implemented Assembly Bill 2868 by ordering SCE, PGE, and SDGE to procure up to an additional 500 MW of distributed energy storage, including no more than 125 MW of customer-sited energy storage.

Small-Scale Energy Storage Trends in the Rest of the United States

After California, the states with the most small-scale storage power capacity in 2018 were Hawaii, Vermont, and Texas, and much of this capacity was installed in the residential sector (Figure 11). Minimal small-scale storage power capacity in the industrial sector existed outside of California. In the commercial sector, small-scale storage was mostly available in Hawaii and New York, as well as other states, notably in Georgia, Illinois, and Utah.

Figure 11. Small-scale energy storage capacity outside of California by sector (2018)

power capacity
megawatts



Source: U.S. Energy Information Administration, Form EIA-861, *Annual Electric Power Industry Report*

Small-scale energy storage system are typically owned by end-users. Direct-connected storage systems are installations not located at an ultimate customer's site but rather in front of the meter or connected directly to a distribution system or both. In Vermont, Green Mountain Power Corporation reported the largest amount of direct-connected battery storage power capacity. Green Mountain operated front-of-the meter battery storage systems for customers that totaled 5.5 MW of power capacity in 2018.

Market and Policy Drivers

As discussed previously, battery storage is technologically capable of serving many applications, each with benefits for one or more participants in the electricity system, including transmission and distribution system operators, generation resources, and consumers. However, the functional ability of storage to serve these applications can be limited or not well defined under existing market rules and other policies. This situation has begun to change as the technology has matured and industry stakeholders in some regions have gained experience financing, procuring, and operating storage installations. Most of the activity has been led by wholesale market operators and state-level regulators.

Wholesale Market Rules

ISOs and RTOs are independent, federally-regulated non-profit organizations that ensure reliability and optimize supply and demand bids for wholesale electric power. They are technology neutral and must ensure market rules do not unfairly preclude any resources from participating, as enforced by the Federal Energy Regulatory Commission (FERC). Many existing market rules may not take into account the unique operating parameters and physical constraints of battery storage as both a consumer and producer of electricity. However, recent actions by FERC and ISOs/RTOs have begun to carve a path for storage to participate in the individual markets.

A notable example is FERC Order 755, issued in 2011, which required ISO/RTO markets to provide compensation to resources that can provide faster-ramping frequency regulation. As a result of Order 755, PJM split its frequency regulation market into a fast-ramping service and a slower-ramping service. By the end of 2015, more than 180 MW of large-scale battery storage capacity had come online in the PJM territory. However, in 2015 PJM began observing operational issues due to overdependence on the fast-ramping regulation service, which mainly consisted of resources such as batteries with duration restrictions, as opposed to the slower-ramping service, which generally consisted of resources which could be operated much longer (but took longer to come online)[16]. PJM thus changed its frequency regulation signals, and installations of large-scale battery storage in the region stalled since PJM made these changes.

Other system operators have also implemented relevant changes to market rules, including developing unique asset classes for storage, specifying participation models, lowering minimum size requirements, allowing for aggregation, and defining duration requirements. However, these regions have not seen large-scale battery storage deployment at the same level as PJM. In February 2018, FERC issued Order No. 841 requiring system operators to remove barriers to the participation of electric storage resources in the capacity, energy, and ancillary services markets. Each ISO/RTO under FERC jurisdiction was required to revise its tariff to include market rules that recognize the physical and operational characteristics of electric storage resources and to implement the revisions upon FERC's approval of

[16] PJM , "Fast Response Regulation (RegD) Resources Operational Impact," July 01,2017. https://www.pjm.com/~/media/committees-groups/committees/oc/20150701-rpi/20150701-fast-response-regulation-resources-operational-impact-problem-statement.ashx

tariff compliance. As of May 2020, all ISO/RTO's had filed multiple tariff revisions but none have been fully approved by FERC.

State-Level Policy Actions

Other than FERC activities described in the previous section, federal policies involving energy storage have been limited.[17] Most policy actions involving energy storage have been at the state level and include setting procurement mandates, establishing incentives, and requiring incorporation of storage into long-term planning mechanisms.

Policy Actions in California

California has introduced several measures related to energy storage. In 2013, the California Public Utility Commission (CPUC) implemented Assembly Bill 2514 by setting a mandate for its investor-owned utilities to procure 1,325 MW of energy storage across the transmission, distribution, and customer levels by 2020. All of the capacity must be operational by 2024. In May 2017, CPUC implemented Assembly Bill 2868 by ordering its investor-owned utilities to procure up to an additional 500 MW of distributed energy storage, including no more than 125 MW of customer-sited energy storage. The Self-Generation Incentive Program, which provides financial incentives for installing customer-sited distributed generation, has designated $48.5 million in rebates for residential storage systems 10 kW or smaller and $329.5 million for storage systems larger than 10 kW.

Press reports in 2017 indicated that 100 MW, or about 37% of existing battery storage power capacity in California, was installed in response to a leak at the Aliso Canyon Natural Gas Storage Facility outside Los Angeles in October 2015.[18] According to these reports, in May 2016, to help address resulting reliability risks as a result of constraints on natural gas supply, the CPUC authorized the Southern California Edison electric utility to hold an expedited solicitation for energy storage. As a result, 62 MW of battery storage capacity was added to the system in December 2016. In addition, the CPUC expedited an ongoing procurement of 38 MW of battery storage by San Diego Gas and Electric, which was installed in early 2017.

Policy Actions in the Rest of the United States

As of May 2020, five states besides California have also set energy storage mandates or targets. In 2015, Oregon passed House Bill 2193-B, directing two electric utilities to each procure 5 MWh of storage energy capacity by 2020. In August 2018, Massachusetts enacted House Bill 4857 ("An Act to Advance Clean Energy"), directing the Massachusetts Department of Energy Resources set an energy storage target of 1,000 MWh by 2025. In October 2018, New York announced a target of 3,000 MW of energy storage by 2030. In May 2018, New Jersey enacted the Clean Energy Act, P.L. 2018, which set a target of 2,000 MW of energy storage by 2030. In February 2020, Virginia passed House Bill 1526, which set a 3,100 MW energy storage goal by 2035. In addition, some states, such as Nevada, allow storage systems

[17] One exception is the investment tax credit (ITC), which is a credit to income tax liability proportional to the capital expenditures originally intended for certain renewable energy technologies, including solar and wind. Energy storage installed at a solar or wind facility can be considered part of the energy property of the facility and can receive a portion of the tax credit.

[18] Green Tech Media, "Tesla, Greensmith, AES Deploy Aliso Canyon Battery Storage in Record Time," January 31, 2017, https://www.greentechmedia.com/articles/read/aliso-canyon-emergency-batteries-officially-up-and-running-from-tesla-green#gs.bvJdDKY

to be included in state-level renewable portfolio standards. Aside from targets, some states have provided financial incentives for energy storage installations, including grants, support for pilot projects, and tax incentives. In 2018, Maryland passed Senate Bill 758, offering a tax credit of 30% on the installed costs for residential and commercial systems.

Many states require utilities to produce integrated resource plans (IRPs) that demonstrate each utility's ability to meet long-term demand projections using a combination of generation, transmission, and energy efficiency investments, while minimizing costs. Incorporating storage into IRPs can be a challenge because storage is different from conventional electricity generators and demand-side resources. For example, storage has unique operational constraints, can be interconnected at various points throughout the system, can serve a variety of applications, and is faced with policy and regulatory uncertainty that may affect system profitability. Nonetheless, some states have begun to require utilities to include storage in integrated resource plans, including Arizona, California, Connecticut, Colorado, Florida, Indiana, Kentucky, Massachusetts, New Mexico, North Carolina, Oregon, Utah, Virginia, and Washington. New York and Vermont include storage in their state energy plans.[19]

[19] PV Magazine, "Utilities are increasingly planning for energy storage," December 7, 2017, https://pv-magazine-usa.com/2017/12/07/utilities-are-increasingly-planning-for-energy-storage-w-charts/

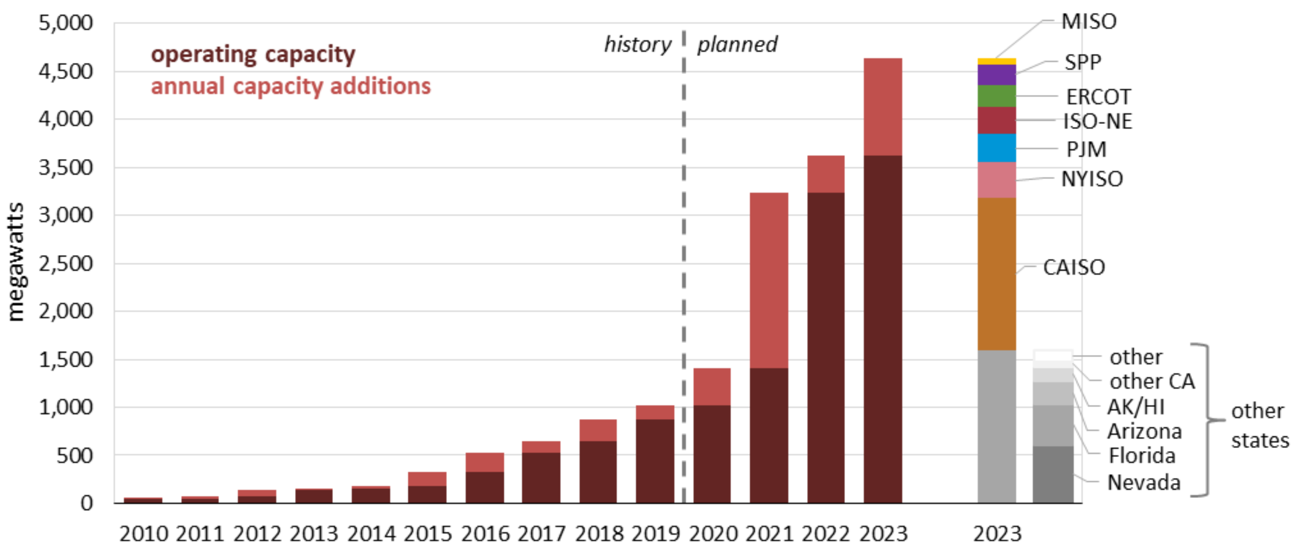
Ongoing Trends

For the short term, EIA assesses future battery capacity installation trends using planned generator additions reported by project developers, both for stand-alone battery storage systems and for those co-located with other electricity generating technologies such as solar or wind. EIA provides long-term projections on future battery capacity installations in the *Annual Energy Outlook*.

Near-Term Planned Capacity Additions (2020–23)

As of December 2019, project developers reported to EIA that they planned to make 3,616 MW of large-scale battery storage operational in the United States between 2020 and 2023. Given the short planning period required to install a storage facility, the reported planned capacity does not necessarily reflect all the possible builds during this period, but the reported planned capacity can be used as an indicator of trends.

Figure 12. Large-scale battery storage cumulative power capacity (2010–2023)



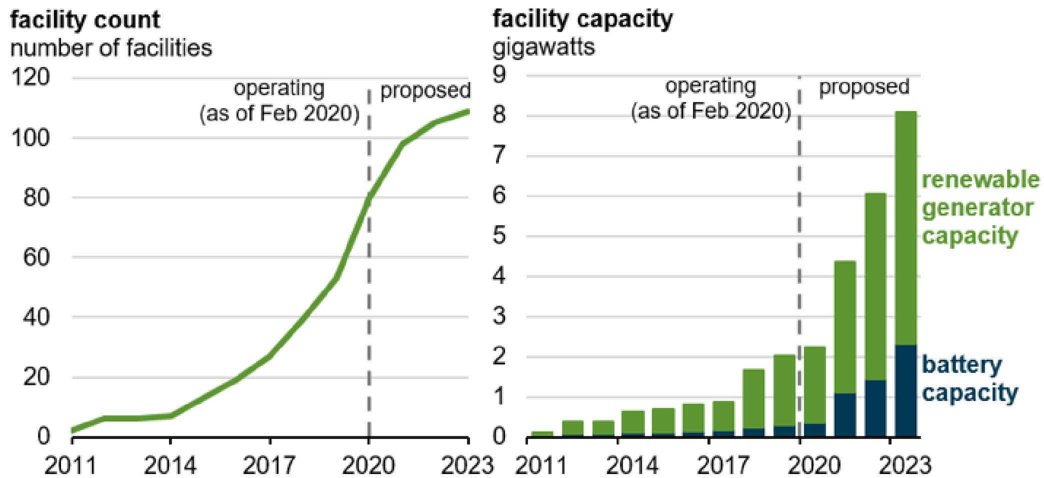
Source: U.S. Energy Information Administration, Form EIA-860M, *Preliminary Monthly Electric Generator Inventory*

California accounted for 38% of planned battery storage power capacity reported as of December 2019. These planned additions put California in line to meet its energy storage mandate (Assembly Bill 2514), which requires its investor owned utilities to install 1,325 MW of energy storage across the transmission, distribution, and customer levels by 2024. New York and Massachusetts also have state mandates for energy storage and have planned battery storage projects in the upcoming years. Virginia and New Jersey have mandates but have not reported any planned energy storage builds to EIA (See Market and Policy Drivers for more information). Several states without policy mandates show relatively strong growth in storage in the upcoming years, including Nevada, Florida, and Arizona.

Co-Located Battery Storage Projects

Pairing renewable energy power plants with energy storage is a trend of increasing importance as the cost of energy storage declines. The number of solar and wind generation sites co-located with battery storage systems has increased from 19 paired sites in 2016 to 53 sites in 2019. Data reported for proposed projects suggest that the number of co-located sites may double by 2023 from 2019 levels.

Figure 13. Count and capacity of renewable plus storage facilities (2011–2023)



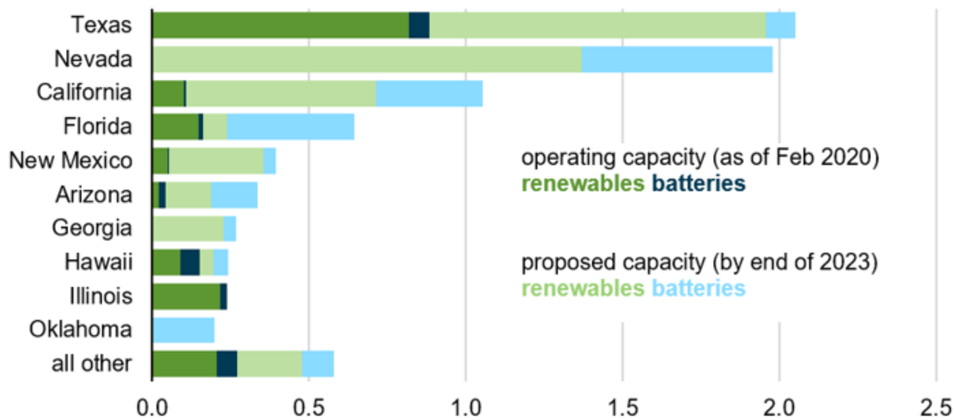
Source: U.S. Energy Information Administration, Form EIA-860M, *Preliminary Monthly Electric Generator Inventory*; U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report.*

Among the benefits of these co-located projects, the most critical is the ability to take advantage of common onsite infrastructure to store renewable-generated energy produced during periods of low electricity prices and low demand, and later supply that stored energy to the grid when both demand and electricity prices are higher. Solar and wind technologies are the more common generators that benefit from battery storage because of their intermittent operation. The benefits of later pairing battery storage can also be realized even after the renewable energy power plant has initially entered into operation. More than 25 solar and wind power plants have added battery storage systems after their original operation date. As of February 2020, more than 90% of the operating capacity from co-located battery and renewable generation sites were located in nine states. Texas had the most co-located battery storage capacity with 886 MW (renewable plus storage capacity) as of February 2020 (Figure 14). On average, existing co-located projects have a renewable nameplate capacity to battery power capacity ratio of 6:1, and planned projects have a power capacity ratio of 2:1. As of 2019, 10 of the 53 co-located facilities accounted for more than half of the combined renewable and battery storage capacity. Of all operating battery storage capacity in the United States as of 2019, 25% was installed in paired systems, while of all the operating solar capacity in the United States, only 2% was in paired with an energy storage system. By December 2023, 2.3 gigawatts (GW) of the 4.9 GW (47%) of operating battery storage is planned to be paired onsite with renewable generation.

Figure 14. Operating and planned renewable plus storage capacity, top 10 states

power capacity

gigawatts



Source: U.S. Energy Information Administration, Form EIA-860M, *Preliminary Monthly Electric Generator Inventory*; U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*.

Long-Term Projected Capacity Additions (2020–2050)

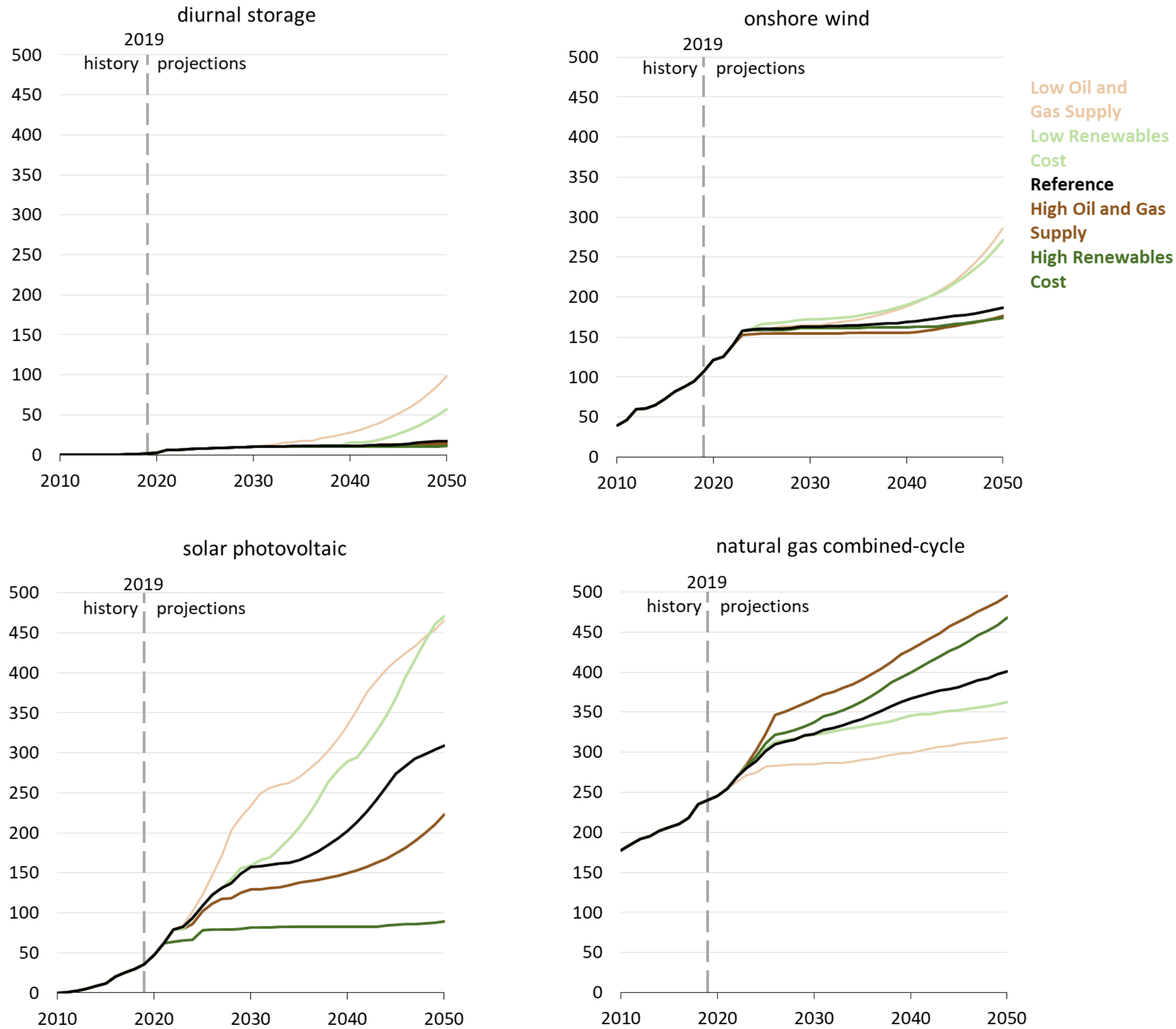
The *Annual Energy Outlook 2020* (AEO2020) provides projections to 2050 on the supply and demand needs for energy markets in the United States. The Reference case, which assumes implementation of current U.S. laws and policies, projects large-scale battery storage capacity to grow from 1 GW in 2019 to 17 GW in 2050 (Figure 15Figure 14).

In addition to the Reference case, AEO2020 examines the sensitivity of model results to changes in various assumptions. In the Low Renewables Cost case, where the costs of renewable technologies are assumed to decline at a faster rate, ending at 40% lower than the Reference case by 2050, higher levels of energy storage support increased solar and wind capacity additions. In the Low Oil and Gas Supply case, less availability of natural gas results in higher natural gas prices. Because natural gas-fired combined-cycle generating units and solar facilities compete with each other, increased natural gas prices promote the growth of solar and thus storage as in the Low Renewables Cost case. In addition, the high price of natural gas used by combustion turbine peaking units allows more market opportunity for energy arbitrage, which also supports the growth of energy storage. These factors contribute to the Low Oil and Gas Supply case showing the most storage capacity additions of any of the AEO2020 projections.

Figure 15. AEO2020 power capacity by case and selected technology, 2050

power capacity

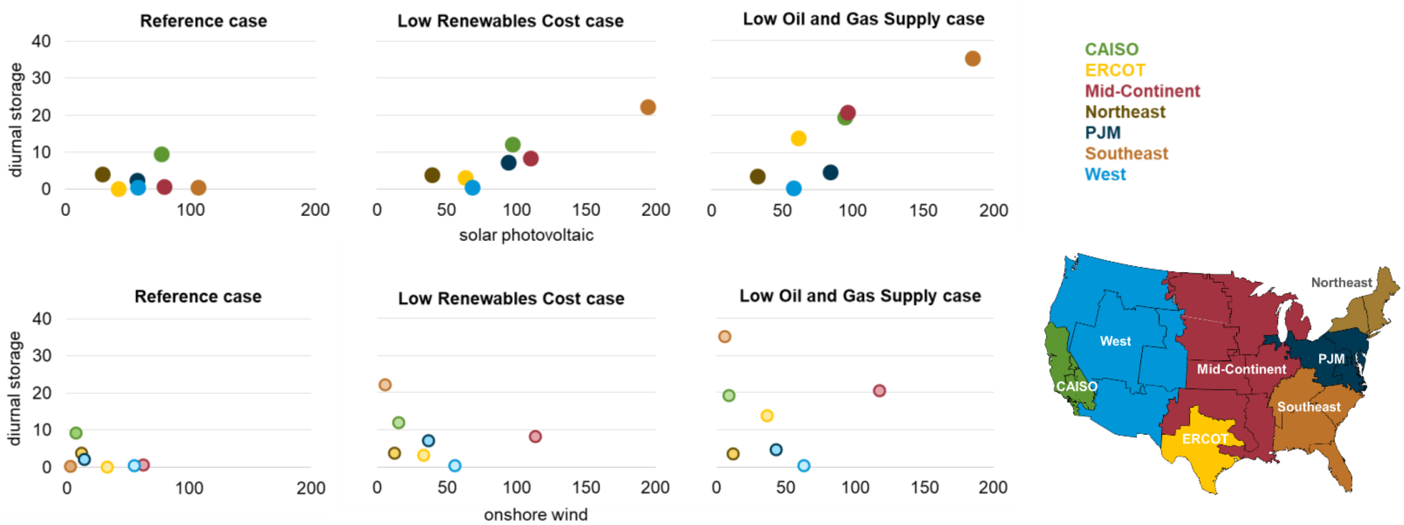
gigawatts



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2020*

When looking at the regional trends in the Reference case and side cases (Figure 16), growth in energy storage capacity follows growth in solar photovoltaic (PV) capacity, but it does not correlate strongly with growth in wind generation capacity. The Southeast region is very sensitive to the varying assumptions in the side cases, showing strong growth relative to the Reference case in both the Low Oil and Gas Supply case and Low Renewables Cost case. All cases show limited storage growth in the Northeast, PJM, and West regions.

Figure 16. AEO2020 regional diurnal storage versus solar photovoltaic power and wind capacity, 2050
power capacity
gigawatts



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2020*

Because long-term planning models are designed to deliver multi-decade results with many complex interactions, modelers often have to simplify their modeling of energy storage technologies. One simplification that has significant consequences for the representation of energy storage technologies is the temporal resolution of the model. EIA's AEO2020 included energy storage as a four-hour battery system that can be used to avoid curtailments of excess solar- and wind-generated electricity, shift energy within a day, and help meet regional reliability requirements; however, modeling sub-hourly markets, such as battery systems participating in frequency response, remains a challenge. As a result, EIA's AEO projections as shown do not represent all of the available storage technology options nor the full suite of applications that storage can serve. See the list of possible applications for storage in the Current Applications section of this report.

EIA has been collaborating with other modeling entities on a multi-model comparison[20] to enhance the representation of technologies that challenge conventional long-term planning model design, such as wind, solar, and energy storage. The representation of battery storage in the AEO will continue to develop as the markets and applications for energy storage evolve.

[20] Cole, Wesley, et al, *Variable Renewable Energy in Long-Term Planning Models: A Multi-Model Perspective*, November 2017, https://www.energy.gov/eere/analysis/downloads/variable-renewable-energy-long-term-planning-models-multi-model-perspective.

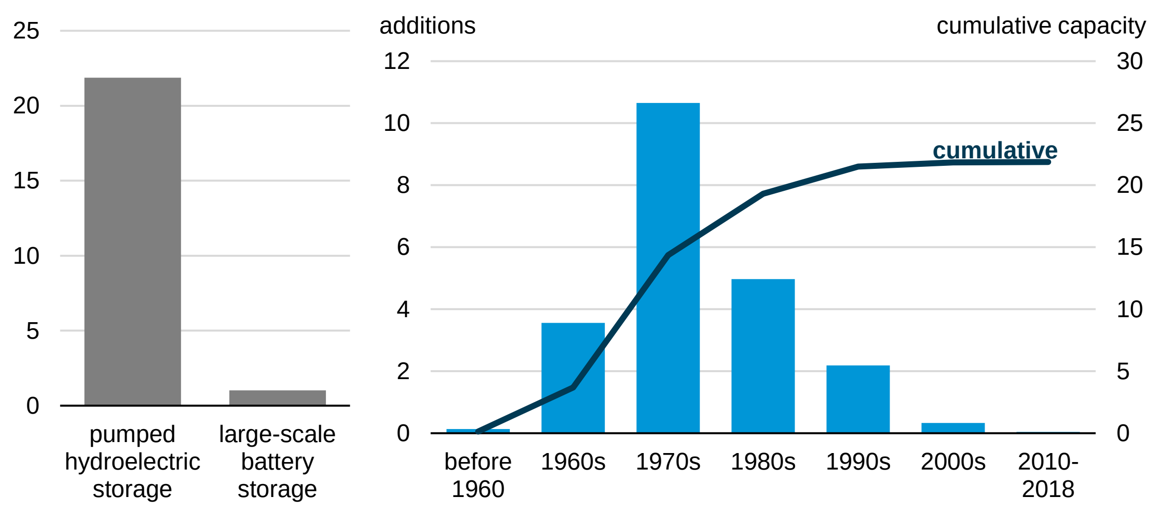
Appendix A: Other Storage Technologies

This report has focused primarily on electrochemical energy (or battery) storage; however, energy storage can take other forms including electrical, thermal, and mechanical. Electrical energy storage includes capacitors and superconductors. Thermal storage includes water, ice, molten salts, and ceramics. Mechanical includes technologies such as hydroelectric pumped storage, flywheels, and compressed-air energy storage (CAES).

Hydroelectric pumped storage uses electricity to pump water into an elevated reservoir so it can be used to drive a hydroelectric turbine when electricity is needed. Although the United States has significantly more operating hydroelectric pumped storage capacity than battery storage capacity, most of it was installed in the 1970s and early 1980s (Figure 17). California, Virginia, and South Carolina account for most of the existing hydroelectric pumped storage capacity. The largest single facility in the United States was installed in 1985 in Bath County, Virginia, and has a capacity of 3 GW.

Figure 17. Hydroelectric pumped storage capacity (1960–2018)

power capacity
gigawatts



Source: U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*

Flywheels store energy by using an electric motor to speed up a spinning mass, which can then be used later to spin a turbine to produce electricity. To reduce losses, the mass is spinning in a nearly frictionless enclosure. Flywheels are well suited to provide power-oriented applications that require many charge and discharge cycles. Three large-scale flywheel systems are currently operating in the United States: a 20 MW system in New York, a 20 MW system in Pennsylvania, and a 2 MW system in Alaska. One standby flywheel system of 5 MW currently exists in Texas.

CAES uses electricity to compress air and store it in an underground cavern. The air is then expanded through a turbine when electricity is needed. The only operable large-scale CAES system in the United States is a 110 MW system that was installed in Alabama in 1991 by PowerSouth Energy Cooperative.

The Apex Bethel Energy Center is a 317 MW CAES system in Texas that is expected to enter operation in 2022.

Thermal storage systems take excess energy produced during the day to heat salt or other materials that can be used later to power a steam turbine. Thermal storage can also be used as a distributed energy resource, for example, by chilling water overnight to use for space cooling during summer days. All existing large-scale thermal energy storage in the United States uses concentrated solar power (CSP) technology. CSP reflects rays from the sun to a receiver to produce steam directly or to heat up alternative fluids, which are used to generate steam through a heat exchanger. The steam is then run through a turbine to generate electricity. Some of these alternative heat transfer or storage fluids can store energy for long durations, and they can be used to generate steam and electricity at night using thermal solar energy gathered during the day. Of the eight CSP projects currently in operation (totaling 1,775 MW) only Arizona Solar One LLC's Solana Generating Station plant in Arizona (295 MW) and Tonopah Solar Energy LLC's Crescent Dunes Solar Energy plant in Nevada (110 MW) employ energy storage.

Other energy storage technologies are in different phases of development but have yet to see significant deployment in large-scale grid applications.

Bulk Energy Storage Increases United States Electricity System Emissions

Eric S. Hittinger*† and Inês M. L. Azevedo‡

View Author Information

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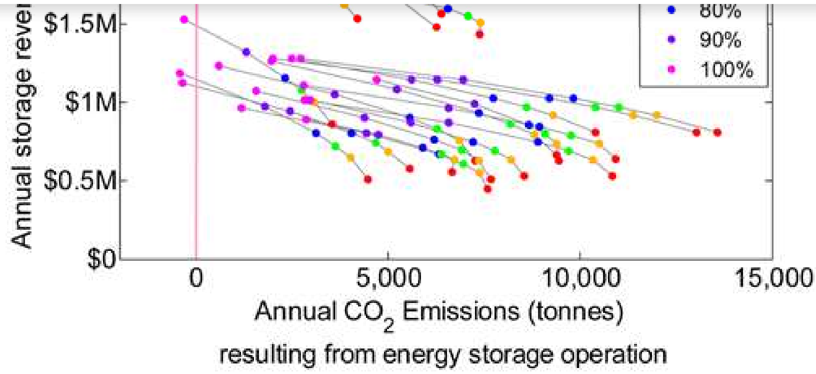
Publication Date: January 28, 2015
https://doi.org/10.1021/es505027p

SUBJECTS:



Bulk energy storage is generally considered an important contributor for the transition toward a more flexible and sustainable electricity system. Although economically valuable, storage is not fundamentally a “green” technology, leading to reductions in emissions. We model the economic and emissions effects of bulk energy storage providing an energy arbitrage service. We calculate the profits under two scenarios (perfect and imperfect information about future electricity prices), and estimate the effect of bulk storage on net emissions of CO_2, SO_2, and NO_x for 20 eGRID subregions in the United States. We find that net system CO_2 emissions resulting from storage operation are nontrivial when compared to the emissions from electricity generation, ranging from 104 to 407 kg/MWh of delivered energy depending on location, storage operation mode, and assumptions regarding carbon intensity. Net NO_x emissions range from −0.16 (i.e., producing net savings) to 0.49 kg/MWh, and are generally small when compared to average generation-related emissions. Net SO_2 emissions from storage operation range from −0.01 to 1.7 kg/MWh, depending on location and storage operation mode.

Supporting Information

Annualized net emissions resulting from storage operation, extended sensitivity analysis, list of the locations and price data used in this work, and results under NERC region-level MEFs. This material is available free of charge via the Internet at http://pubs.acs.org.

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The California ISO is monitoring COVID-19 developments, and is taking proactive steps to protect staff, customers, community, and the electric grid. Learn more.

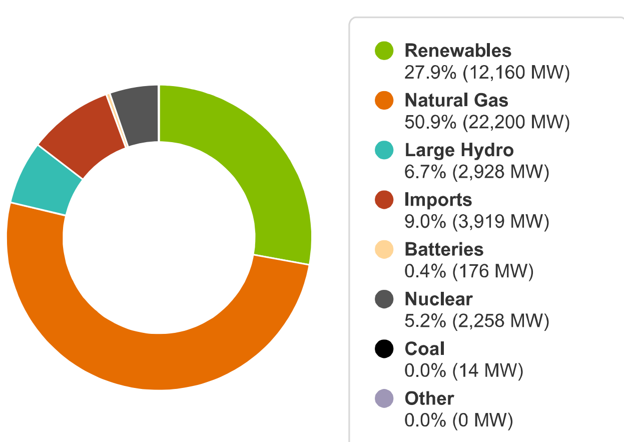
Grid status View all alerts	Northern California	Southern California	VEA Region
Flex Alert			
Restricted Maintenance Operations			

Supply and renewables AS OF 16:45

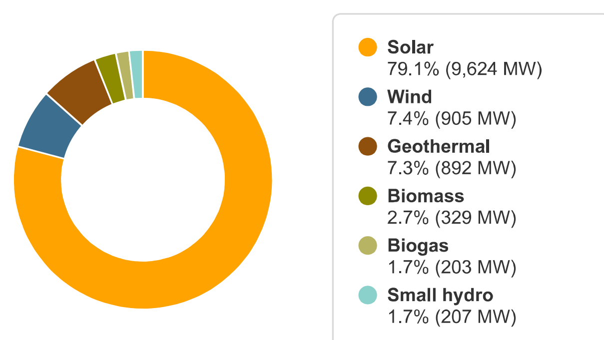
About supply

43,498 MW	**12,160 MW**	**9,624 MW**	**905 MW**
Current demand	Current renewables	Current solar	Current wind

Current supply



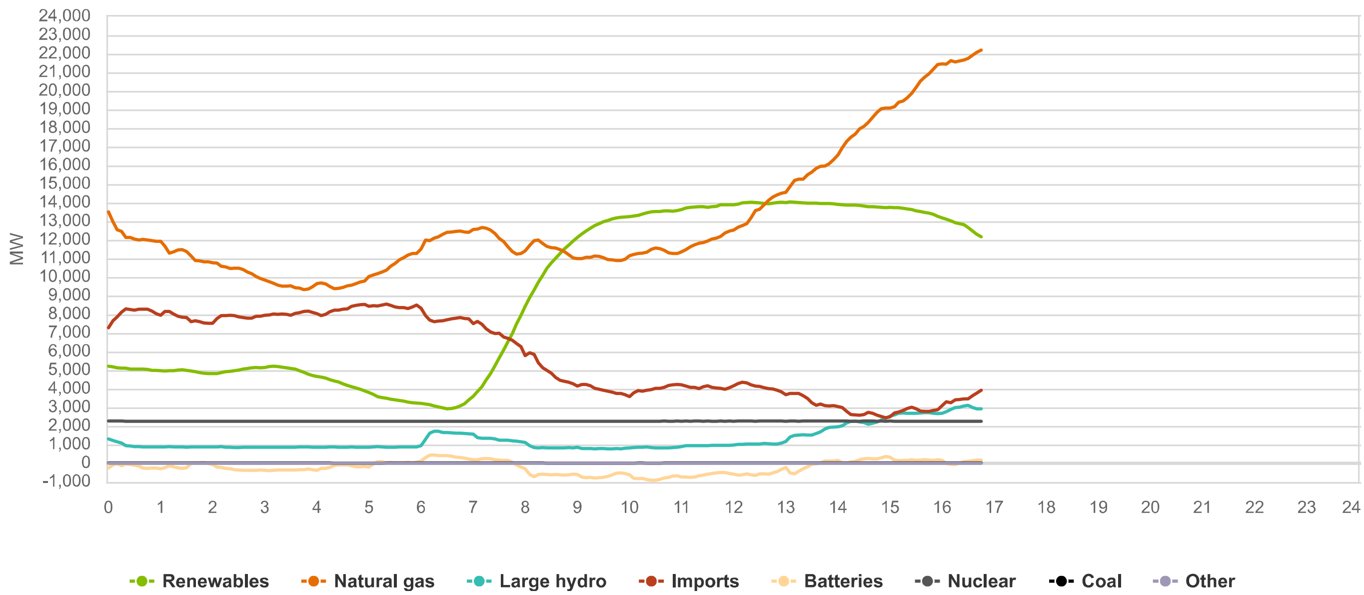
Current renewables



Supply trend

Energy in megawatts broken down by resource in 5-minute increments.

09/08/2021 Options Download



Renewables trend

Energy in megawatts broken down by renewable resource in 5-minute increments.

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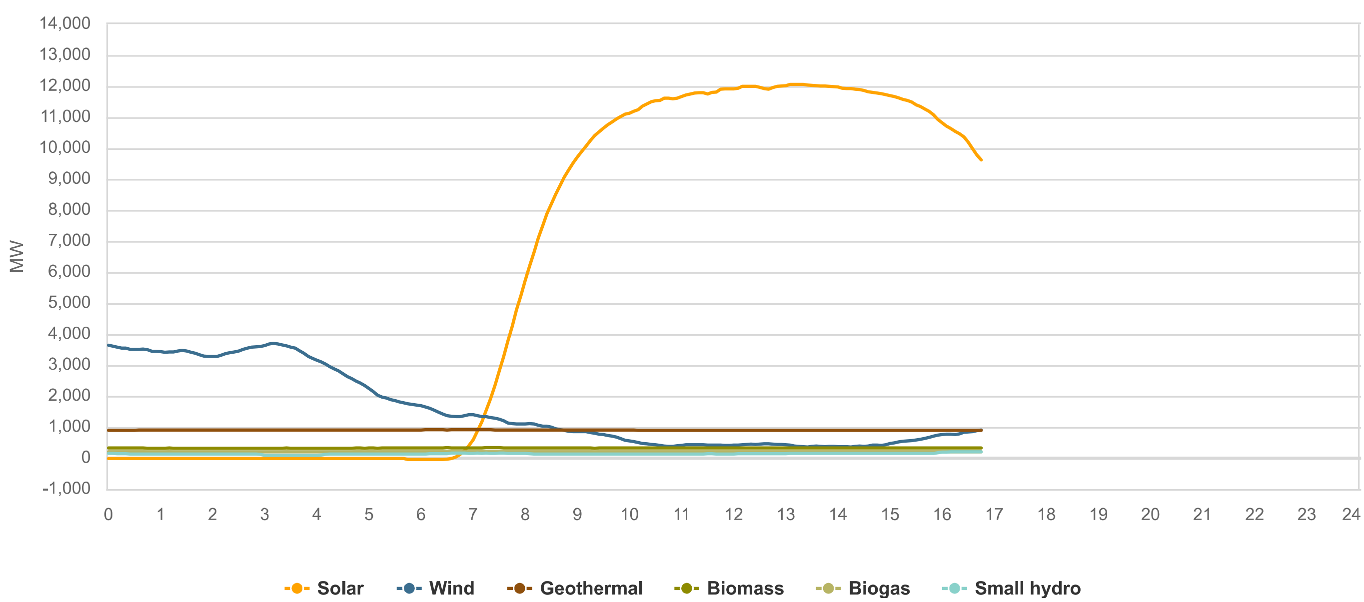
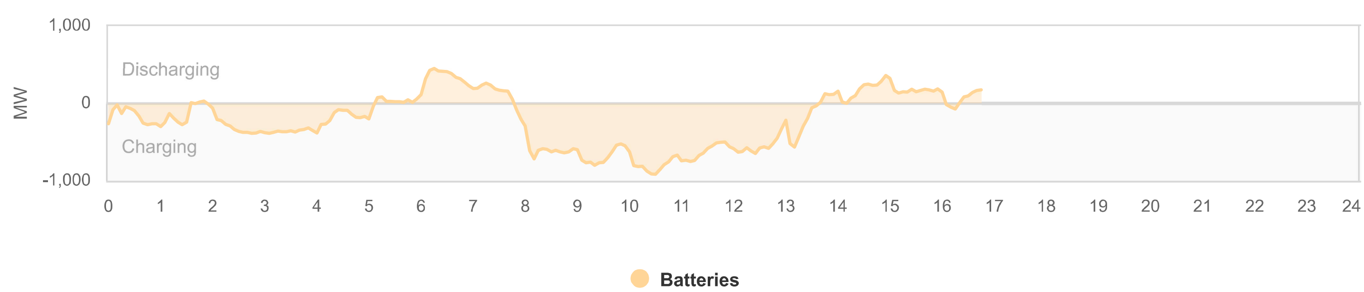


Daily renewables watch | Wind and solar curtailment report | Key Statistics | Monthly Renewables Performance Report

Batteries trend

Energy in megawatts in five-minute increments.

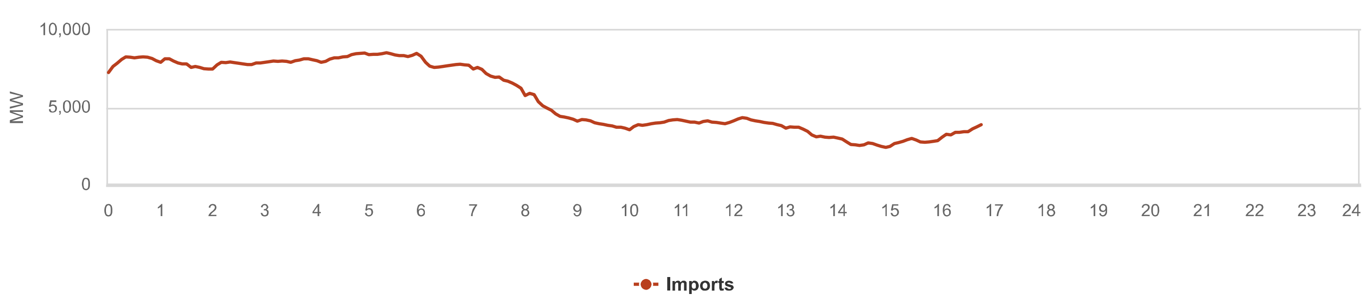
09/08/2021 Download



Imports trend

Unspecified imported energy, in megawatts, scheduled for delivery within the ISO balancing authority.

09/08/2021 Download



Today's Outlook charts are designed to summarize forecasts and actual loads. The demand and net demand trend data do not include dispatchable pump loads or battery storage that is charging on the system. This data is for informational purposes only, and should not be used for determining actual billing values or operational planning.

Data is subject to change without notice.
For official data, visit OASIS. For official emissions data, visit CARB.

CalEEMod®

California Emissions Estimator Model®

User's Guide

Version 2016.3.1

Prepared for:
California Air Pollution Control Officers Association (CAPCOA)

Prepared by:
BREEZE Software, A Division of Trinity Consultants
in collaboration with South Coast Air Quality Management District and the California Air Districts

Date:
September 2016

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Contents

List of Appendices

1 Introduction

This User's Guide (Guide) to the California Emission Estimator Model (CalEEMod)® is meant to give the user an introduction on how to use the program as well as to document the detailed calculations and default assumptions made in associated appendices. The purpose of CalEEMod is to provide a uniform platform for government agencies, land use planners, and environmental professionals to estimate potential emissions associated with both construction and operational use of land use projects. It is intended that these emission estimates are suitable for quantifying air quality and climate change impacts as part of the preparation of California Environmental Quality Act (CEQA) documents. In addition, individual districts may rely on the model's emission estimates to show compliance with local agency rules.

CalEEMod utilizes widely accepted methodologies for estimating emissions combined with default data that can be used when site-specific information is not available. Sources of these methodologies and default data include but are not limited to the United States Environmental Protection Agency (USEPA) AP-42 emission factors, California Air Resources Board (CARB) vehicle emission models, studies commissioned by California agencies such as the California Energy Commission (CEC) and CalRecycle. In addition, some local air districts provided customized values for their default data and existing regulation methodologies for use for projects located in their jurisdictions. When no customized information was provided and no regional differences were defined for local air districts, then state-wide default values were utilized. Since resource data and regulations are constantly changing, local agencies should be consulted to determine whether there are any circumstances when updated values should be used in place of the defaults currently incorporated into CalEEMod. A majority of CalEEMod's default data associated with locations and land use is derived from surveys of existing land uses. For any project that substantially deviates from the types and features included in the surveys, site-specific data that are supported by substantial evidence should be used, if available.

The model provides a number of opportunities for the user to change the defaults in the model; however, users are required to provide justification for all changes made to the default settings (e.g., reference more appropriate data sources) in the Remarks box provided at the bottom of the screen before the user will be able to proceed to the next screen. Further, the user should make every effort to ensure that correct data is entered, including the choice and percent reduction of mitigation most applicable to the land use project being evaluated.

1.1 Purpose of Model

CalEEMod provides a simple platform to calculate both construction emissions and operational emissions from a land use project. It can calculate both the daily maximum and annual average for criteria pollutants as well as annual greenhouse gas (GHG) emissions. The output from these calculations can be used in the preparation of quality and GHG analyses in CEQA documents such as Environmental Impact Reports (EIRs) and Negative Declarations. For projects located in the jurisdiction of San Luis Obispo APCD, the model can also calculate the sum of reactive organic gas (ROG) and nitrogen oxide (NO_X) emissions on a rolling quarterly basis. In addition, CalEEMod contains default values for estimating water and energy use which may be useful for preparing hydrology and energy analyses in other sections of a CEQA document. Specifically, the model can aid the user by conducting the following calculations:

- Short-term construction emissions associated with the demolition, site preparation, grading, building, coating, and paving from the following sources:
  - Off-road construction equipment;
  - On-road mobile equipment associated with workers, vendors, and hauling;
  - Fugitive dust associated with grading, demolition, truck loading, and on-road vehicles traveling along paved and unpaved roads. (Fugitive dust from wind blown sources such as storage piles and inactive disturbed areas, as well as fugitive dust from off-road vehicle travel, are not quantified in CalEEMod, which is consistent with approaches taken in other comprehensive models.)
  - Architectural coating activities *(including the painting/striping of parking lots)* and paving (ROG).
- Operational emissions for fully built-out land use development from the following sources:
  - On-road mobile vehicle traffic generated by the land uses;
  - Fugitive dust associated with roads;
  - Architectural coating activities (ROG);
  - Off-road equipment (e.g., forklifts, cranes) used during operation;
  - Landscaping equipment;
  - Emergency generators, fire pumps, and process boilers;
  - Use of consumer products, parking lot degreasers, fertilizers/pesticides, and cleaning supplies (ROG);
  - Wood stoves and hearth usage;
  - Natural gas usage in the buildings;
  - Electricity usage in the buildings (GHG only);
  - Electricity usage from lighting in parking lots and lighting, ventilation and elevators in parking structures;
  - Water usage per land use (GHG only); and,
  - Solid waste disposal per land use (GHG only).
- One-time vegetation sequestration changes
  - Permanent vegetation land use changes
  - New tree plantings

- Mitigation adjustments to both short-term construction and operational emissions. Several of the mitigation measures described in CAPCOA's Quantifying Greenhouse Gas Mitigation Measures[1] have been incorporated into CalEEMod.

[1] Available at: http://www.capcoa.org/wp-content/uploads/2010/11/CAPCOA-Quantification-Report-9-14-Final.pdf

2 Program Installation

The program is distributed and maintained by the California Air Pollution Control Officers Association[2]. The most recent version can be downloaded from www.caleemod.com.

2.1 Operating System Requirements

CalEEMod was programmed by Trinity using Microsoft SQL Compact Edition in conjunction with a Visual Basic Graphical User Interface (GUI). CalEEMod requires the following system requirements:

- Microsoft Windows 8 or 10 Operating System with Microsoft .NET Framework 3.5 (includes .NET 2.0 and 3.0)
- Microsoft Windows XP, Vista, or 7 Operating System with Microsoft .Net Framework 4 or higher
- Microsoft SQL Server Compact 3.5 SP2
- 300 Mb hard drive space available

2.2 Installation Procedures

To install

1. Be sure to uninstall any previous versions of CalEEMod before installing a new version as some file names will be the same potentially confusing the computer. To uninstall for most computers, under Settings, Control Panel, Programs and Features, highlight CalEEMod and then click 'uninstall.'

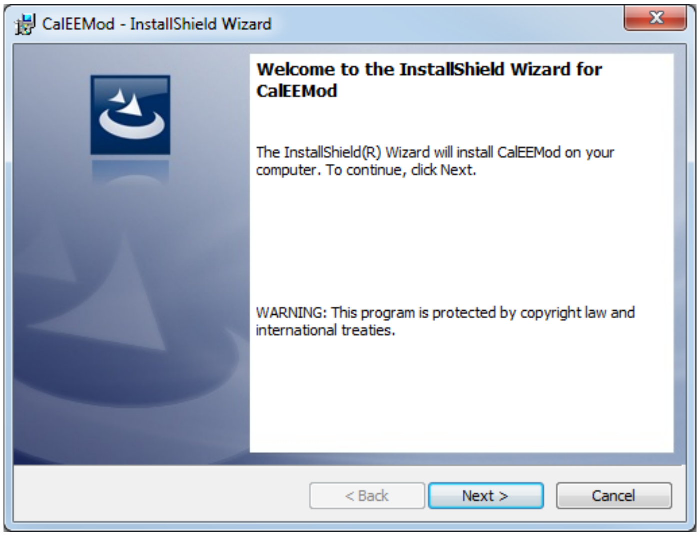
2. Ensure you have the required Microsoft .Net framework installed on your machine. Microsoft .NET Framework 3.5 is available free from Microsoft at https://www.microsoft.com/en-us/download/details.aspx?id=21, and Microsoft .NET Framework 4.0 or higher is available free from Microsoft at https://www.microsoft.com/en-us/download/details.aspx?id=17851. Once this file is downloaded, unzip the file anywhere on your computer and run the installation file (setup.exe) and follow the instructions on Microsoft's website to locate the appropriate .msi file. To install Microsoft SQL Server Compact 3.5 SP2, go to https://www.microsoft.com/en-us/download/details.aspx?id=5783. For 32-bit computers, you will need to install SSCERuntime_x86-ENU.msi. For a 64-bit computer, you will need to install both the 32-bit and the 64-bit version of the SQL Server Compact 3.5 SP2 MSI files because the existing SQL Server Compact 3.5 applications may fail if only the 32-bit version of the .msi file is installed on the 64-bit computer.

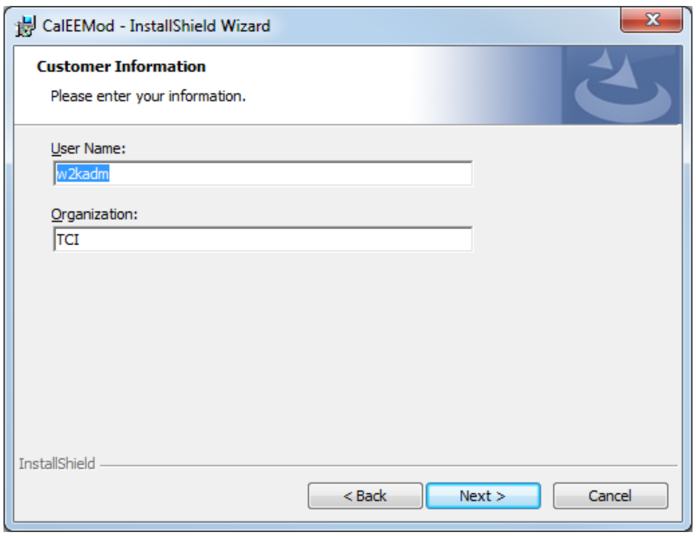
3. From www.CalEEMod.com, download the installation file (CalEEMod2016.3.1.exe), click on file and follow the instructions. Pages 5 through 7 show screen shots of the CalEEMod InstallShield Wizard.

4. The default directory for CalEEMod is C:\CalEEMod\. To select an alternative directory location, choose Custom Installation[3].

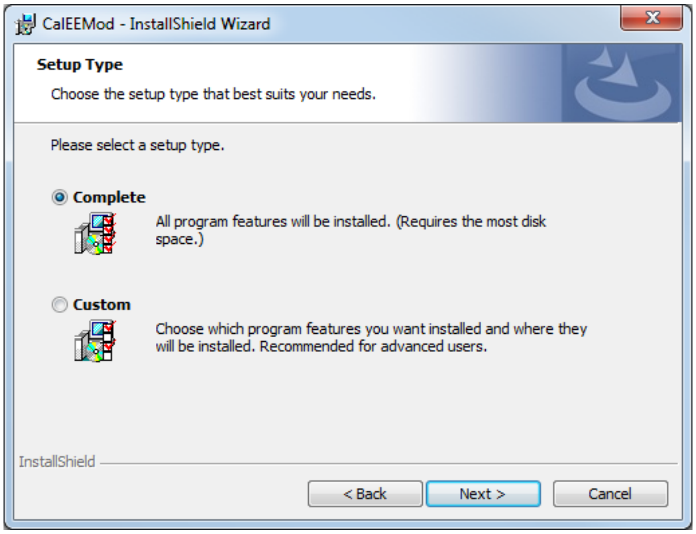
5. Click Next until the installation has completed, then click Finish to exit the installer.

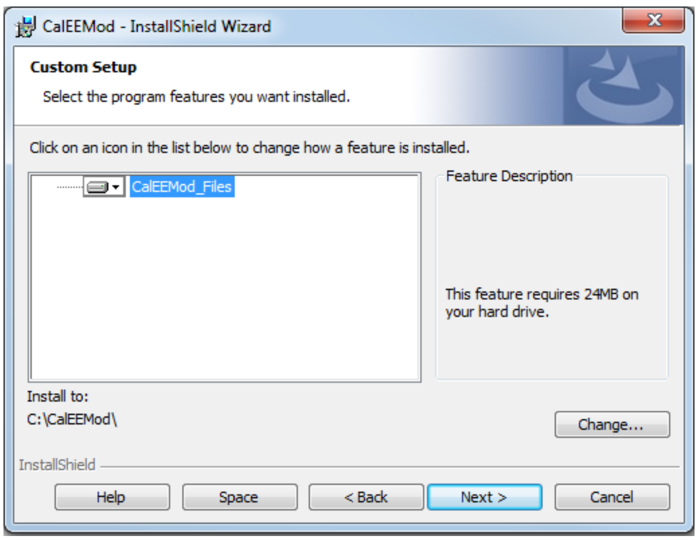
6. If you have any further trouble installing CalEEMod, verify that you have appropriate user privileges and that your computer meets the operating system requirements.

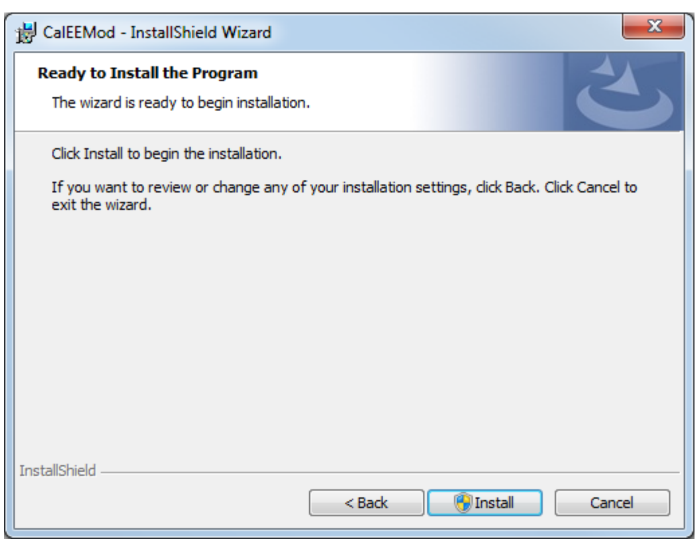


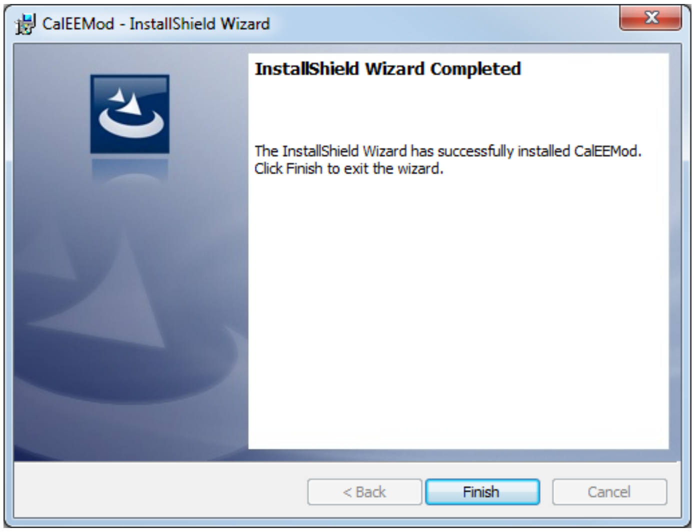


3 If you use Windows Vista, 7, 8 or 10, file privileges may not allow access rights to some folders during program operations such as C:\Program Files\.


CalEEMod - InstallShield Wizard
Setup Type
Choose the setup type that best suits your needs.
Please select a setup type.
Complete
All program features will be installed. (Requires the most disk space.)
Custom
Choose which program features you want installed and where they will be installed. Recommended for advanced users.
InstallShield
< Back
Next >
Cancel

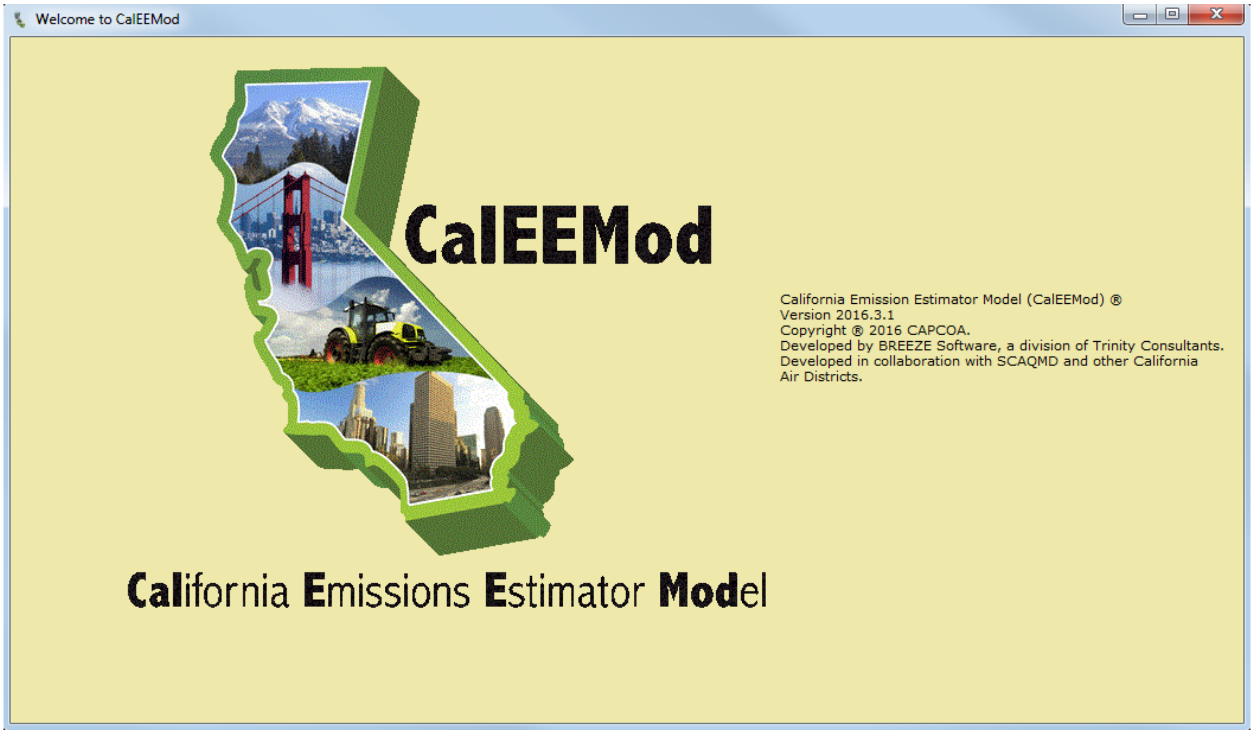

CalEEMod - InstallShield Wizard
Custom Setup
Select the program features you want installed.
Click on an icon in the list below to change how a feature is installed.
CalEEMod_Files
Feature Description
This feature requires 24MB on your hard drive.
Install to:
C:\CalEEMod\
Change...
InstallShield
Help
Space
< Back
Next >
Cancel


CalEEMod - InstallShield Wizard
Ready to Install the Program
The wizard is ready to begin installation.
Click Install to begin the installation.
If you want to review or change any of your installation settings, click Back. Click Cancel to exit the wizard.
InstallShield
< Back
Install
Cancel



2.3 Starting CalEEMod

After the installation is complete, a CalEEMod short cut icon will be appear on the desktop and CalEEMod will appear in the list of Programs available from the Start Button. To start the model, select CalEEMod from the program files or double click on the CalEEMod short cut icon.



3 Using CalEEMod

3.1 Key Features

CalEEMod is comprised of a linear series of screens with each screen designed with an individual purpose to define features of the project such as project characteristics, construction schedule and equipment, operational activity, mitigation measures, etc. The user will need to input basic information about the project such as location, land use type (e.g., residential, commercial, retail, etc.) and project size and the model will populate later screens with pre-determined defaults. The user may override the defaults to input more accurate, project-specific information as appropriate.

The figure on page 10 identifies some key features of CalEEMod which are described below.

1. Menu Bar: A drop down menu bar is found on all screens. For example, the Home menu controls file features such as New Project, Open Project, Save Project, and Save As Project. The Help menu will link to appropriate information for the relevant screen from this User's Guide. All of the other menus will allow navigation between the screens in any order.

2. Screen Name: Identifies the name of the current screen.

3. Default Button: This button allows the user to restore the program defaults after the user has changed any default values on the screen. User-entered values will be highlighted in yellow to clearly indicate the defaults that have been changed. The user will be prompted to specify whether the default should be restored for the current or last cell on the screen or for the entire screen. The Import csv option will allow the user to load in a .csv file for a specific data grid. Clicking on the Undo button will allow the user to cancel or undo the previous action.

4. Remarks: This section is located at the bottom of each screen and it requires the user to enter comments regarding any defaults that have been replaced with user-defined values. The Remarks section is meant to assist project reviewers to determine or assess the justification for user-defined values entered.

5. Next Button: When the user clicks on this button, the next sequential screen will appear. As the user progresses through the model, later screens will also show a Previous button that will take the user to the previous screen.

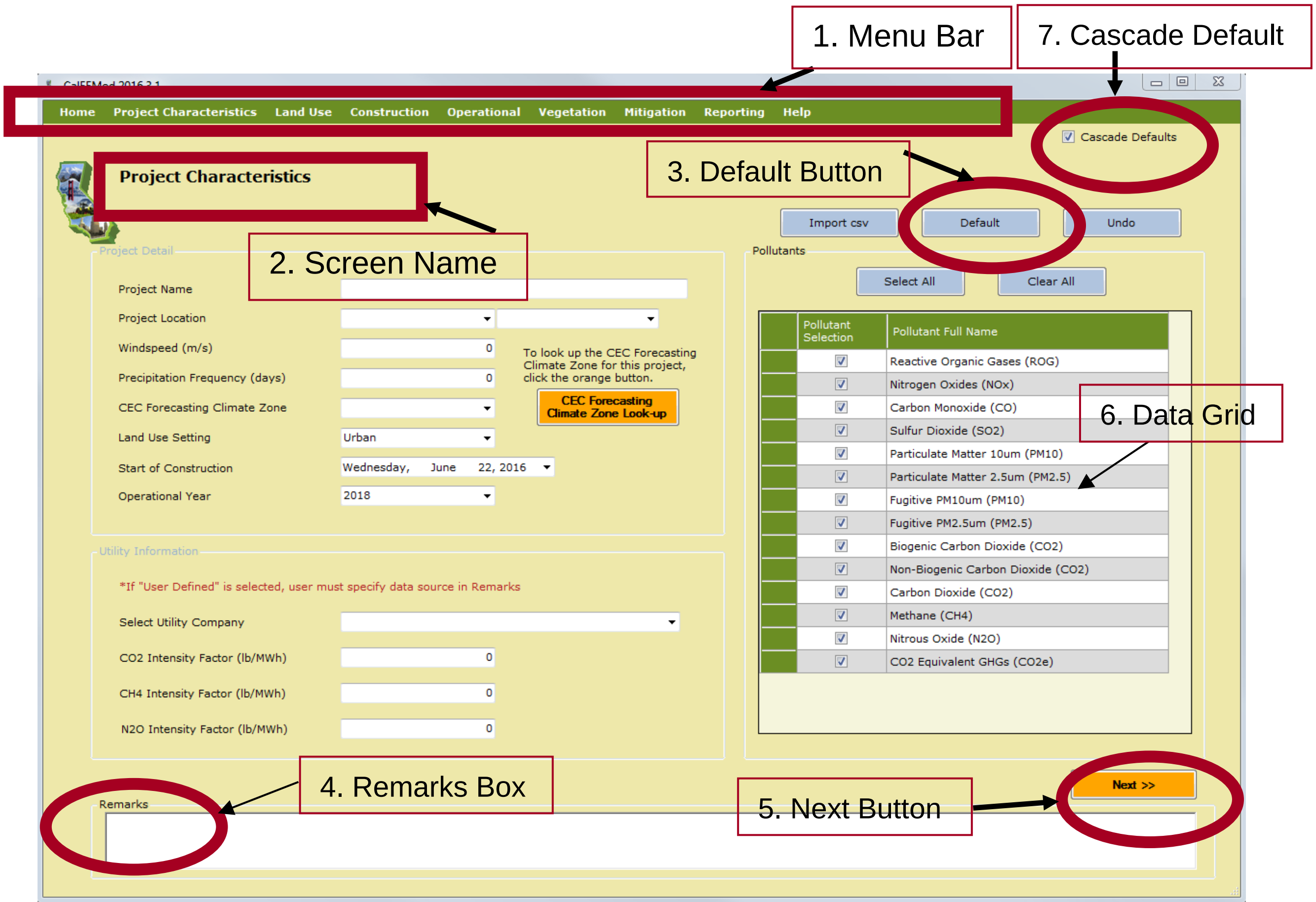
6. Data Grid: This is a common box where values for the variables defined across the top are to be filled in with data. The number of rows will automatically be adjusted based on the number of rows of information required to define the information. On some data grids, the last row may have an asterisk (*) and once the user begins adding information to this row, a new row will be added at the end. To delete a row, select the desired row to delete, and hit the delete button on your keyboard. (Deleting information is generally allowed unless the data grid contains a fixed list such as the Pollutant selection list.)

Scroll bars (both horizontal and vertical) may also occur on some data grids, as appropriate.

7. Cascade Defaults: CalEEMod has a feature that freezes the automatic downloading of the programmed defaults. Each input screen displays a box called Cascade Default which will be automatically checked to populate defaults in future screens. However, if user unchecks the Cascade Default box, no defaults will be populated in subsequent screens and the user will need to input project-specific data. Unless all the necessary input parameters required for a proper analysis are known, the user should run the model at least once with "Cascade Default" button checked to allow the defaults to be populated. Then, if the user would like to change the project's parameters (e.g., number of dwelling units, building square footage, etc.) without cascading new defaults in later screens, then the user should uncheck the Cascade Default box when in the Land Use screen. This feature may be helpful when the defaults are replaced with project-specific information (e.g., construction schedule, construction equipment, water use, energy use, etc.) and the user would like to evaluate different project scenarios with the same basic project information (e.g., land use type, location, etc.). In addition, by unchecking the Cascade Default box, the following will occur:

   - The defaults in *ALL* subsequent screens will be frozen.
   - Any changes that are made to screens that follow the Land Use screen (e.g., adding a new construction phase) will not cascade defaults relating to that change or add new tabs (e.g., trips and VMT, dust material movement). Thus, the user will need to manually input project-specific information in order for the impacts to be calculated.
   - If any changes to land use type (e.g., from single family housing to a hospital) are made, the subsequent screens will not reflect the new land use type causing some incorrect calculations (e.g., impacts from energy and water use) to be performed.

   When changing or adding a land use type, the user should click on the Cascade Default button so the future screens will be populated with appropriate defaults and the correct calculations specific to the changed or added land use type will occur.


1. Menu Bar
7. Cascade Default
Home
Project Characteristics
Land Use
Construction
Operational
Vegetation
Mitigation
Reporting
Help
Cascade Defaults
Project Characteristics
3. Default Button
Import csv
Default
Undo
2. Screen Name
Project Detail
Pollutants
Select All
Clear All
Project Name
Project Location
Windspeed (m/s)
Precipitation Frequency (days)
CEC Forecasting Climate Zone
Land Use Setting
Urban
Start of Construction
Wednesday, June 22, 2016
Operational Year
2018
To look up the CEC Forecasting Climate Zone for this project, click the orange button.
CEC Forecasting Climate Zone Look-up
Pollutant Selection
Pollutant Full Name
Reactive Organic Gases (ROG)
Nitrogen Oxides (NOx)
Carbon Monoxide (CO)
Sulfur Dioxide (SO2)
Particulate Matter 10um (PM10)
Particulate Matter 2.5um (PM2.5)
Fugitive PM10um (PM10)
Fugitive PM2.5um (PM2.5)
Biogenic Carbon Dioxide (CO2)
Non-Biogenic Carbon Dioxide (CO2)
Carbon Dioxide (CO2)
Methane (CH4)
Nitrous Oxide (N2O)
CO2 Equivalent GHGs (CO2e)
6. Data Grid
Utility Information
*If "User Defined" is selected, user must specify data source in Remarks
Select Utility Company
CO2 Intensity Factor (lb/MWh)
CH4 Intensity Factor (lb/MWh)
N2O Intensity Factor (lb/MWh)
4. Remarks Box
5. Next Button
Next >>
Remarks

3.2 Home

The Home tab on the file menu bar that controls the file saving and opening features. The available options are:

- New Project
- Open Project
- Save
- Save As
- Exit

The user should select Open Project to open a project that has been previously created and saved or New Project to create a new project. Note that opening a previously saved project will remove any information that has been entered into the GUI unless it has been saved to a file. Save will save the currently loaded project database as a Microsoft Excel file and this file can be closed, and then re-opened later. Save As will allow the user to change the name of the saved project file. Exit will close CalEEMod. The Microsoft Excel file can be edited following the format of the save file to quickly make edits outside of the Graphical User Interface (GUI) but the user will still need to use the GUI in order to report the results. This can be most useful in making changes to construction lists. Data for individual tabs can be uploaded as a .csv file in various places in CalEEMod to minimize the data entry.

3.3 Defining a Project

In order to define a project, the user will need to enter information on both the Project Characteristics screen and the Land Use screen. After entering information on these two screens, CalEEMod will populate all of the other information required to calculate unmitigated construction (unless there is demolition, grading, or site preparation) and operation emissions using default data. If demolition, grading, and/or site preparation activities are part of the project, then the user will need to enter additional information on the appropriate construction screens, including but not limited to, the amount of material to be demolished and transported to or from the site. If site-specific information is not needed for the project, the user can skip this part and jump to the Mitigation screen and enter mitigation measures. After completing the Mitigation screen, the user can proceed to the Reporting screen to select the type of report to be generated for the project.

3.4 Altering Default Data

CalEEMod was designed with default assumptions supported by substantial evidence to the extent available at the time of programming. The functionality and content of CalEEMod is based on fully adopted methods and data. However, CalEEMod was also designed to allow the user to change the defaults to reflect site- or project-specific information, when available, provided that the information is supported by substantial evidence as required by CEQA. If the user chooses to modify any defaults, an explanation will be required in the Remarks box found at the bottom of the screen to justify and support the modification before the user will be able to proceed to the next screen. Modifications to defaults and the explanations are noted in the output report. Comments in the Remarks box are also included in the report and alert reviewers of modifications to the defaults. Comments are important because they show the user's justification for the modifications, which allows the reviewers the ability to determine whether or not the modifications are appropriate and sufficiently justified.

3.5 Mitigation

Common construction mitigation measures that impact the calculations in CalEEMod have been incorporated as options for the user to select. It is important to note that compliance with fugitive dust rules vary widely by district and include requirements to reduce dust. Even though the fugitive dust rules contain requirements that when implemented, have the effect of mitigating dust emissions, these requirements are not considered to be mitigation per se. For these reasons, requirements such as percentage adjustments to fugitive dust rules have not been incorporated into the unmitigated fugitive dust calculations.

Several mitigation measures from CAPCOA's Quantifying Greenhouse Mitigation Measures have been incorporated including combinations and caps when using multiple mitigation measures. . CalEEMod was designed to include typical mitigation measures that are some of the more effective measures available to development projects. If mitigation measures are not available as options in CalEEMod, the user can alter the inputs in the program to adjust to account for mitigation measures that may be less common. This will require separate runs of CalEEMod files in order to properly account for unmitigated and mitigated scenarios. For more details regarding mitigation, see Subchapter 4.11.

3.6 Reporting

The Reporting tab allows the user to select the type of report (e.g., annual, winter or summer) to present the results of the calculations. The reports can be viewed on screen and then saved as either a Microsoft Excel file or a .pdf file. For more details regarding reporting, see Subchapter 4.11.

4 Detailed Program Screens

4.1 Project Characteristics

The Project Characteristics screen is starting point where the user enters the project name, project location, and selects utility provider, climate zone, and pollutants to be analyzed. The information entered on this screen will trigger project appropriate default data to populate subsequent screens. Any changes entered on this screen will override any previously entered user-defined data and the corresponding default data. The project name will appear in the reports. Each of the information categories on this screen are described in more detail below.

Project Location

To define the region where the project is located, the user is given the option to select Air District, Air Basin, County, or Statewide. The second drop down box will reveal a list of specific locations to the region selected. If the user selects County, It is important to note that there may be some counties that are shared by multiple Air Districts, Air Basins or District-specific sub-regions and the default values (e.g., on-road vehicle emissions, trip lengths, water supply and treatment electricity use, solid waste disposal rates, amount of paved roads, days of landscaping equipment use, architectural coating emissions, and hearth usage) may vary accordingly. Thus, if the user selects County, the user may also be prompted to select the sub-county area. If you are uncertain about what region to choose for your project location, consult your lead agency.

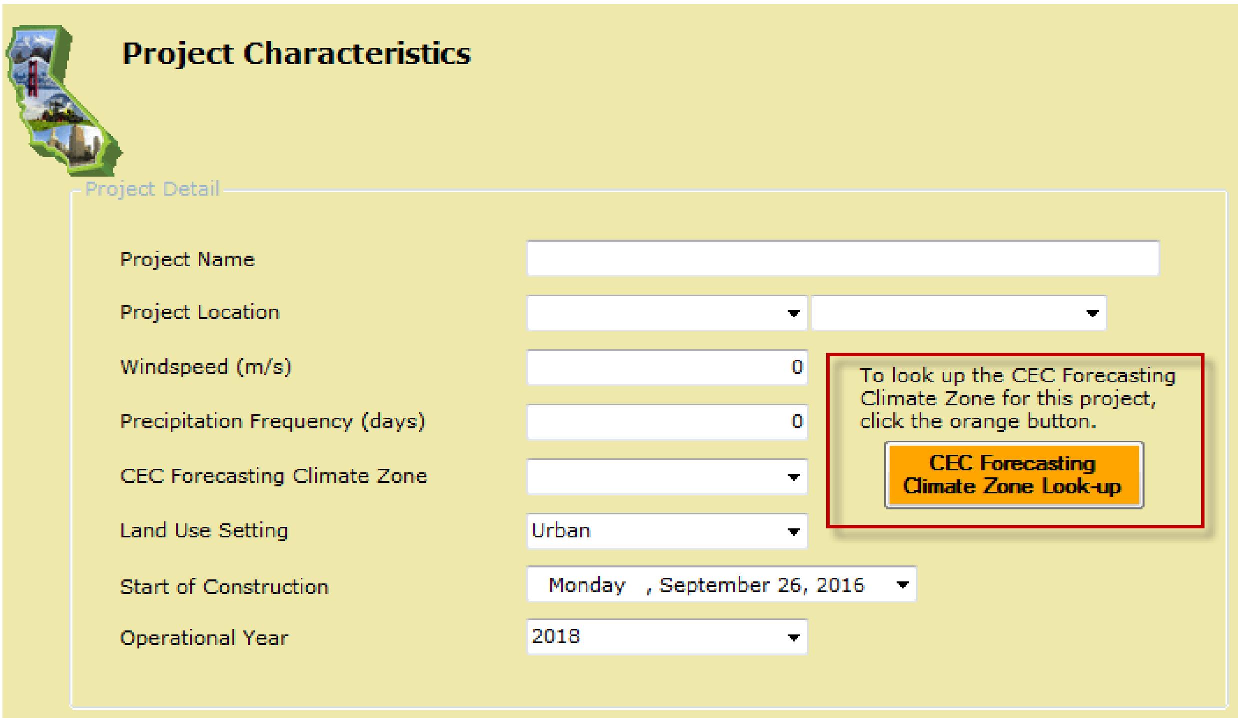
Wind Speed and Precipitation Frequency

Selection of project location will automatically fill in the default wind speed and precipitation frequency. The user can also choose to override this information and enter a different value. The wind speed, in meters per second (m/s), is used in the fugitive dust calculations. Precipitation frequency, e.g. the number of days per year with a precipitation amount measuring greater than 0.01 inches in one day, is used in the fugitive dust calculations.

Climate Zone

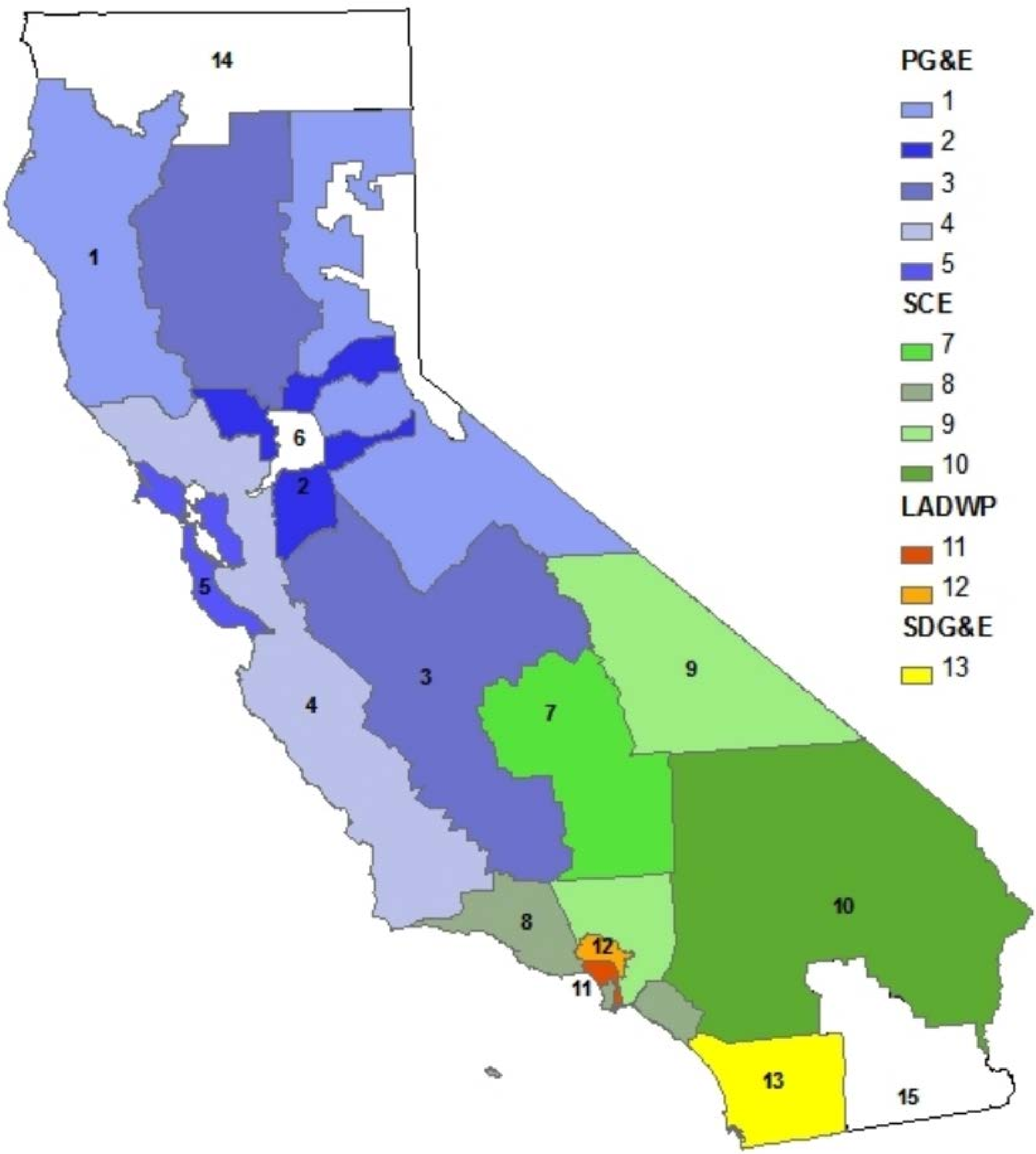
Selection of project location will restrict the climate zones available for the user to choose from based on the climate zones in the project location. The climate zones that have been programmed into CalEEMod are based on the California Energy Commission's (CEC) Forecasting Climate Zones, which are different from the Title 24 Building Climate Zones. The user should determine the correct climate zone by either referring to the figure below or by clicking on the orange button that says "CEC Climate Zone Forecasting Look-up" on the Project Characteristics screen. In addition, the user may also determine the climate zone by city or zip code from the look up tables in Appendix F.

CEC Forecasting Climate Zone Look-up Button



CalEEMod utilizes the Forecasting Climate Zones because the baseline data in the 2002 California Commercial End Use Survey (CEUS) and 2009 Residential Appliance Saturation Survey (RASS), upon which CalEEMod relies, are categorized in this manner. Further information on the calculation of building energy usage, including the application of data specific to the Forecasting Climate Zones, is contained in Appendix E.

CEC Forecasting Climate Zones[4,5]



4 Adapted from Figure ES-2 of CEC. 2010. Residential Appliance Saturation Survey. Available at: http://www.energy.ca.gov/2010publications/CEC-200-2010-004/CEC-200-2010-004-ES.PDF

5 White spaces represent areas served by other electric utilities not included in survey.

Land Use Setting

The Land Use Setting tab is where the user indicates whether the project is located in a rural or urban setting. The user should contact the local air district for the region where the project is located for guidance on the appropriate Land Use Setting to select.

Start of Construction

To indicate when construction of the project will begin, the user will need to insert a date in the Start of Construction field. The date when construction will start triggers a rolling calendar that starts with the construction start date and follows by various construction phases that will be populated with default date ranges in the Construction screen.

Operational Year

CalEEMod is currently designed to key off of one year to initiate the beginning of the full operation of the project. Thus, to indicate when the project will begin operation activities, the user will need to insert a year. CalEEMod will use this year to determine the appropriate emission factors to be used in all operational module calculations. CalEEMod can accommodate the following years for the initial operational year: 2000, 2005, 2010-2035, 2040, 2045, and 2050. To conduct a backcasting analysis by inserting an operational year that occurs in the past, the selection of years is limited to minimize the file size associated with vehicle emission factors. For a project that consists of multiple phases with operation activities occurring over multiple years, the user should run the model multiple times for the various input parameters for each operational year.

Utility Company

From the drop down list, the user will need to select the appropriate utility company that will serve the project location. . When a specific utility is selected, the intensity factors for CO_2, CH_4 and N_2O will be automatically populated with defaults applicable to the specified utility. However, if the utility for the project is not in the drop down list, the user may select User Defined and the user will need to manually enter the various intensity factors. In addition, the user will need to identify the utility in the Remarks section.

The intensity factors are used in various modules to calculate the GHG emissions associated with electricity use. The default values are based on CARB's Local Government Operations Protocol (LGO)[6] for CO_2, updated public utility protocols for CO_2, and E-Grid values for CH_4 and N_2O. Each default CO_2 intensity factor is based on the latest reporting year available for each utility. Appendix D, Table 1.2 provides the default CO_2 intensity factor and reporting year from which the factor was identified for each utility identified in the drop down list. As with other defaults in the model, if a new intensity factor is identified before the defaults in CalEEMod are updated, the user may override the default and provide justification for the change in the Remarks section at the bottom of the Project Characteristics screen.

6 Available at: http://www.arb.ca.gov/cc/protocols/localgov/localgov.htm

Pollutants

CalEEMod provides a list of pollutants with adjacent check boxes for the user to select. Upon starting a new project, all of the boxes are automatically checked and if the boxes remain checked, all pollutants will be quantified and identified in the reports. If user unchecks any of the boxes, the unchecked pollutants will be excluded from the calculations and the reports. Some of the pollutants may overlap other identified pollutants. For example, carbon dioxide (CO_2) is identified on its own, and it is separated into biogenic and non-biogenic categories. In addition, CO_2 Equivalent GHGs represents, all CO_2 emissions plus methane (CH_4) and nitrous oxide (N_2O) as adjusted by their corresponding Global Warming Potential (GWP) weighted value. The GWPs are based on the 2007 IPCC's Fourth Assessment Report (AR4)[7], and are consistent with 2014 CARB's Scoping Plan Update[8].

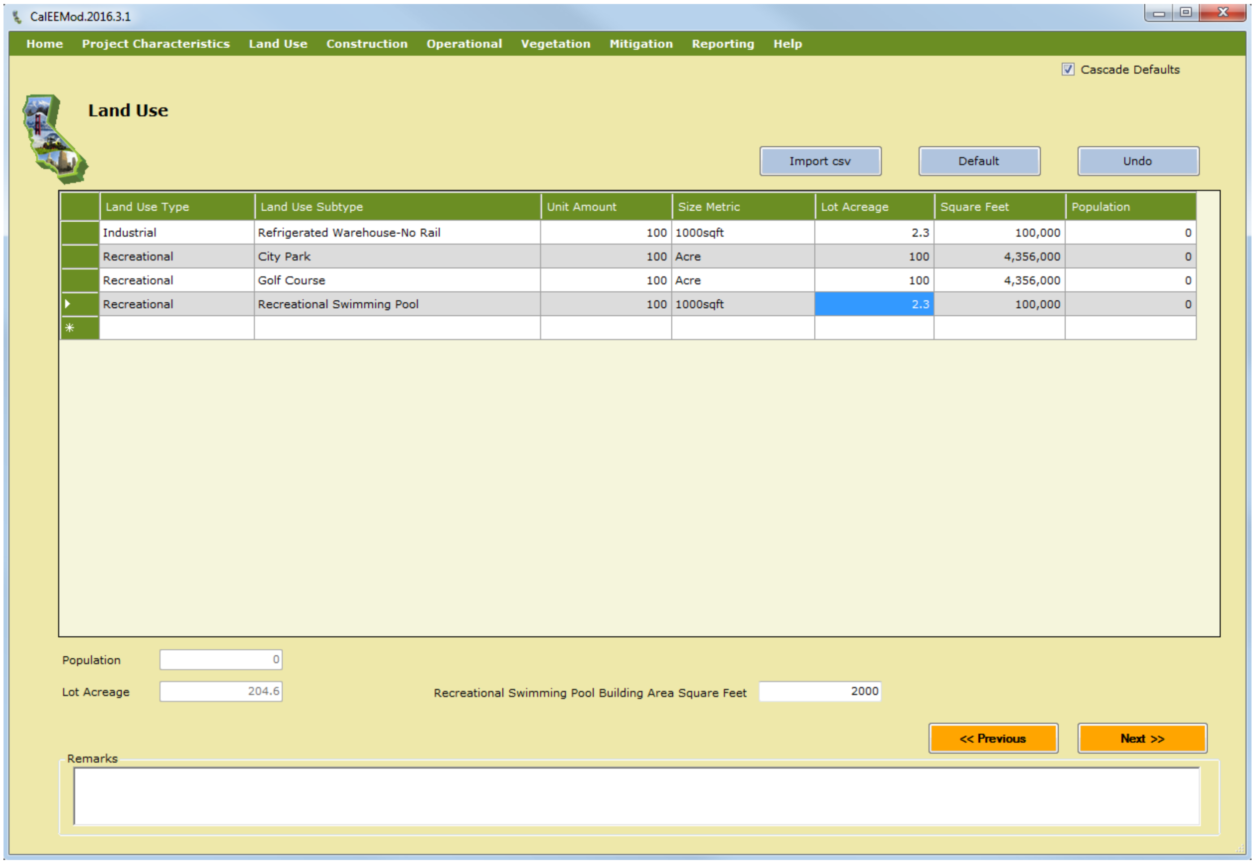
Remarks

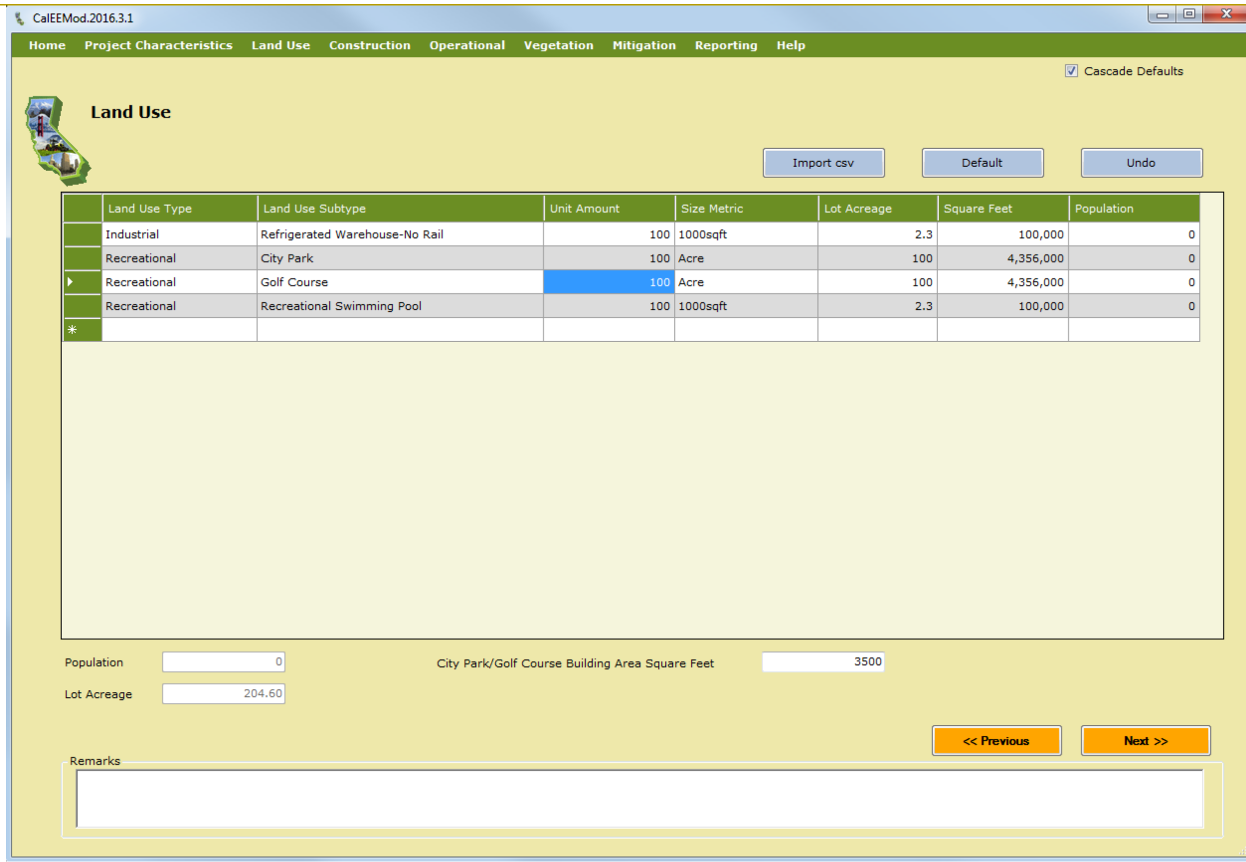
As previously explained in Subchapter 3.4, if the user chooses to modify any defaults, the user will be required to provide an explanation or justification in the Remarks section for incorporating user defined (e.g., non-default) values before the user will be able to proceed to the next screen. Any remarks that are entered will be included in the reports and will assist a reviewer in understanding the reasons for a change in the default value (e.g., new trip rate based on a project-specific traffic study conducted by traffic engineers).

4.2 Land Use

The Land Use screen is where the user identifies the land use(s) that will occur at the project site. The data in the land use types and subtypes, unit amounts, size metric, lot acreage, square feet and population fields determine the default variables that are used in the calculations. It is important to note that for any project that includes a city park, golf course, or recreational swimming pool land use, the user will be prompted to enter the square footage of the buildings associated with these land uses (e.g., restrooms/changing rooms, pro-shop, etc.). By excluding the entire lot size for these three land use types, and instead only using the square footage of the buildings, the calculations for consumer product use will provide a more accurate representation of where these materials are actually used and avoid incorrectly attributing consumer products use to greenspaces and pool water. For more information on the calculations for consumer product use, see Subchapter 4.5, Section 4.5.2.0

7 Available at: https://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_full_report.pdf
8 Available at: http://www.arb.ca.gov/cc/scopingplan/document/updatedscopingplan2013.htm

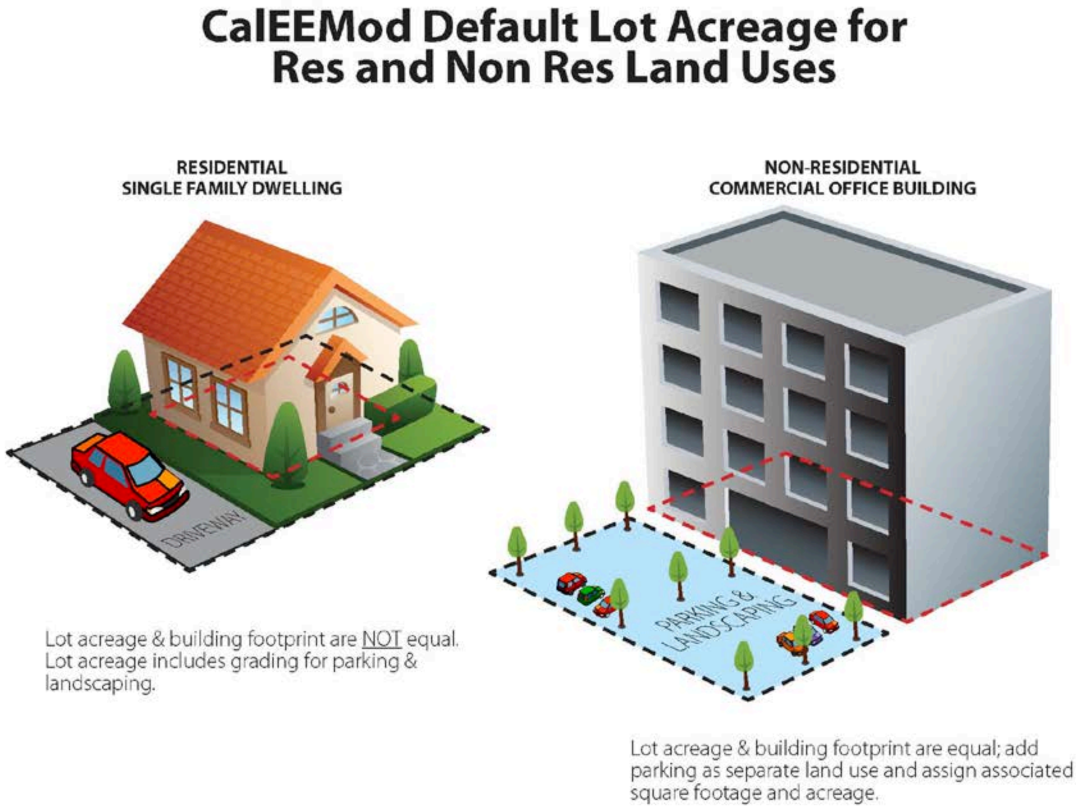

CalEEMod.2016.3.1
Home Project Characteristics Land Use Construction Operational Vegetation Mitigation Reporting Help
Cascade Defaults
Land Use
Import csv
Default
Undo
Land Use Type | Land Use Subtype | Unit Amount | Size Metric | Lot Acreage | Square Feet | Population
Industrial | Refrigerated Warehouse-No Rail | 100 | 1000sqft | 2.3 | 100,000 | 0
Recreational | City Park | 100 | Acre | 100 | 4,356,000 | 0
Recreational | Golf Course | 100 | Acre | 100 | 4,356,000 | 0
Recreational | Recreational Swimming Pool | 100 | 1000sqft | 2.3 | 100,000 | 0
Population 0
Lot Acreage 204.6
Recreational Swimming Pool Building Area Square Feet 2000
<< Previous
Next >>
Remarks



Land Use Type

The Land Use Type tab allows the user to select any of the following primary land use types from a drop down list: Commercial, Educational, Industrial, Parking, Recreational, Residential, and Retail. The 63 different land use types were chosen for inclusion in CalEEMod because each has an established trip rate critical for mobile source calculations.

CalEEMod specifically designates parking areas as a separate land use rather than as a part of an associated non-residential land use (e.g., commercial buildings, retail facilities, etc.). However, no separate parking land use for a driveway or garage needs to be identified for residential land uses because parking is already included in the calculation For more information on how CalEEMod treats parking based on the footprint and lot acreage of residential and non-residential land uses, please refer to the following figure. As depicted, the lot acreage of a residential land use includes the parking and building footprint. For non-residential land uses, the lot acreage is the same as the building footprint, so parking needs to be entered as a separate land use.



For the parking land use subtype, two primary options are available: parking lot or parking structure (e.g., garage). There are four types of parking structures: 1) enclosed; 2) enclosed with an elevator; 3) unenclosed; and, 4) unenclosed with an elevator. The reason for these specific descriptions is so that the model properly accounts for energy impacts associated with ventilation and elevator operations.

For land use subtypes that are not listed (e.g., roads, underground parking, pipelines, etc.) or that do not accurately represent the project being analyzed, each land use subtype has a User Defined option that the user can select. If a User Defined land use subtype is selected, there is no default data (including size metric) that will automatically populate the data fields. Instead, the user will need to manually enter the unit amount, size metric, lot acreage, etc.. If these fields are left blank, no emissions will be calculated for the User Defined land use subtype. Also, whatever size metric (e.g., per acre, per 1000 square foot, etc.) the user chooses for the User Defined land use subtype needs to be consistently applied to all subsequent default values (e.g., gallons of water used *per acre* or *per 1000 square foot*). An alternative approach to entering a User Defined land use subtype would be to choose a land use subtype that most closely fits the project and allow the model to populate the data fields with the defaults. Then, the user can go back through the model and modify the defaults with any known specific project information and enter the required Remarks to explain why the defaults are modified.

Land Use Subtype

63 land use subtypes have been included in CalEEMod and each has an established trip rate that is used for calculating mobile source emissions. By tabbing over to the next column in a row, the user can select a variety of land use subtypes. The user also has the option to select a User Defined land use subtype; however, as explained previously, there is no default data (including size metric) that will automatically populate the data fields. Instead, the user will need to manually enter the unit amount, size metric, lot acreage, etc. Land use subtypes are based primarily on the land use definitions used for (mobile source) trip generation rate information from the Institute of Transportation Engineers (ITE) 9th edition of the Trip Generation Manual. In some cases similar generalized land uses or surrogate data was mapped to some land use subtypes in order to generate the default data needed for various modules.

Table 1: Land Use Subtype Descriptions

Land Use Subtype	Description[1]	ITE Number
RESIDENTIAL		
Apartments High Rise	High-rise apartments are units located in rental buildings that have more than 10 levels and most likely have one or more elevators.	222
Apartments Low Rise	Low-rise apartments are units located in rental buildings that have 1-2 levels.	221
Apartments Mid Rise	Mid-rise apartments in rental buildings that have between 3 and 10 levels.	223
Condo/Townhouse	These are ownership units that have at least one other owned unit within the same building structure.	230
Condo/Townhouse High Rise	These are ownership units that have three or more levels.	232
Congregate Care (Assisted Living)	These facilities are independent living developments that provide centralized amenities such as dining, housekeeping, transportation and organized social/recreational activities. Limited medical services may or may not be provided.	253
Mobile Home Park	Mobile home parks consist of manufactured homes that are sited and installed on permanent foundations and typically have community facilities such as recreation rooms, swimming pools and laundry facilities.	240
Retirement Community	These communities provide multiple elements of senior adult living. Housing options may include various combinations of senior adult housing, congregate care, assisted living, and skilled nursing care aimed at allowing the residents to live in one community as their medical needs change.	255
Single Family Housing	All single-family detached homes on individual lots typical of a suburban subdivision	210

Table 1: Land Use Subtype Descriptions

Land Use Subtype	Description[1]	ITE Number
EDUCATIONAL		
Day-Care Center	A day care center is a facility where care for pre-school age children is provided, normally during the daytime hours. Day care facilities generally include classrooms, offices, eating areas and playgrounds.	565
Elementary School	Elementary schools typically serve students attending kindergarten through the fifth or sixth grade. They are usually centrally located in residential communities in order to facilitate student access and have no student drivers.	520
High School	High schools serve students who have completed middle or junior high school.	530
Junior College (2Yr)	This land use includes two-year junior, community, or technical colleges.	540
Junior High School	Junior High schools serve students who have completed elementary school and have not yet entered high school.	522
Library	A library is a facility that consists of shelved books; reading rooms or areas; and sometimes meeting rooms.	590
Place Of Worship	A church is a building in which public worship services are held. A church houses an assembly hall or sanctuary; it may also house meeting rooms, classrooms and occasionally dining catering or party facilities.	560
University/College (4Yr)	This land use includes four-year universities or colleges that may or may not offer graduate programs.	550
RECREATIONAL		
Arena	Arenas are large indoor structures in which spectator events are held. These events vary from professional ice hockey and basketball to non-sporting events such as concerts, shows, or religious services. Arenas generally have large parking facilities, except when located in or around the downtown of a large city.	460
City Park	City parks are owned and operated by a city.	411
Fast Food Restaurant W/O Drive Thru	This land use includes fast-food restaurants without drive-through windows. Patrons generally order at a cash register and pay before they eat.	933
Fast Food Restaurant With Drive Thru	This category includes fast-food restaurants with drive-through windows.	934
Golf Course	Golf courses include 9, 18, 27 and 36 hole courses. Some sites may also have driving ranges and clubhouses with a pro shop, restaurant, lounge and banquet facilities.	430
Health Club	These are privately-owned facilities that primarily focus on individual fitness or training. Typically they provide exercise classes; weightlifting, fitness and gymnastics equipment; spas; locker rooms; and small restaurants or snack bars.	492

Table 1: Land Use Subtype Descriptions

Land Use Subtype	Description[1]	ITE Number
High Turnover (Sit Down Restaurant)	This land use consists of sit-down, full-service eating establishments with turnover rates of approximately one hour or less. This type of restaurant is usually moderately priced and frequently belongs to a restaurant chain.	932
Hotel	Hotels are places of lodging that provide sleeping accommodations and supporting facilities such as restaurants; cocktail lounges; meeting and banquet rooms or convention facilities; limited recreational facilities and other retail and service shops.	310
Motel	Motels are places of lodging that provide sleeping accommodations and often a restaurant. Motels generally offer free on-site parking and provide little or no meeting space and few supporting facilities.	320
Movie Theater (No Matinee)	Movie theaters consist of audience seating, single or multiple screens and auditoriums, a lobby and a refreshment stand. Movie theaters without matinees show movies on weekday evenings and weekends only; there are no weekday daytime showings.	443
Quality Restaurant	This land use consists of high quality, full-service eating establishments with typical turnover rates of at least one hour or longer. Quality restaurants generally do not serve breakfast, some do not serve lunch; all serve dinner. This type of restaurant usually requires reservations and is generally not part of a chain. Patrons commonly wait to be seated, are served by a waiter, order from menus and pay for meals after they eat.	931
Racquet Club	These are privately-owned facilities that primarily cater to racquet sports.	491
Recreational Swimming Pool	This is a typical recreational swimming pool that may be associated with community centers, parks, swim clubs, etc.	495
PARKING		
Enclosed Parking Structure	This is an enclosed parking structure that may be above or below ground. It is not covered in asphalt. This land use will require lighting and ventilation, and will be more than one floor with no elevator.	
Enclosed Parking with Elevator	This is an enclosed parking structure that may be above or below ground. It is not covered in asphalt. This land use will require lighting and ventilation, and will be more than one floor with an elevator.	
Other Asphalt Surfaces	This is an asphalt area not used as a parking lot (e.g., long driveway, basketball court, etc.)	
Other Non-Asphalt Surfaces	This is a non-asphalt area (e.g., equipment foundation, loading dock area, etc.).	
Parking Lot	This is a typical single surface parking lot typically covered with asphalt. This land use will require lighting.	
Unenclosed Parking Structure	This is an unenclosed parking structure that may be above or below ground. It is not covered in asphalt. This land use will require lighting but not ventilation. It will be more than one floor with no elevator.	
Unenclosed Parking with Elevator	This is a unenclosed parking structure that may be above or below ground. It is not covered in asphalt. This land use will require lighting but not ventilation. It will be more than one floor with an elevator.	

Table 1: Land Use Subtype Descriptions

Land Use Subtype	Description[1]	ITE Number
RETAIL		
Automobile Care Center	An automobile care center houses numerous businesses that provide automobile-related services, such as repair and servicing; stereo installation; and seat cover upholstering.	942
Convenience Market (24 Hour)	These markets sell convenience foods, newspapers, magazines and often beer and wine. They do not sell or dispense motor vehicle fuels (e.g., gasoline and diesel).	851
Convenience Market With Gas Pumps	These markets sell or dispense motor vehicle fuels (e.g., gasoline and diesel), convenience foods, newspapers, magazines and often beer and wine. This includes convenience markets with motor vehicle fueling dispensers where the primary business is the selling of convenience items, not the fueling of motor vehicles.	853
Discount Club	A discount club is a discount store or warehouse where shoppers pay a membership fee in order to take advantage of discounted prices on a wide variety of items such as food, clothing, tires and appliances. Many items are sold in large quantities or in bulk.	857
Electronic Superstore	These are free-standing facilities that specialize in the sale of electronic merchandise.	863
Free-Standing Discount Store	Discount stores offer centralized cashiering and sell products that are advertised at discount prices. These stores offer a variety of customer services and maintain long store hours seven days a week.	815
Free-Standing Discount Superstore	The discount superstore is similar to the free-standing discount stores with the addition that they also contain a full-service grocery department under the same roof that shares entrances and exits with the discount store area.	813
Gasoline/Service Station	This land use includes service stations where the primary business is the fueling of motor vehicles. They may also have ancillary facilities for servicing and repairing motor vehicles.	944
Hardware/Paint Store	These stores sell hardware and paint supplies and are generally free-standing buildings.	816
Home Improvement Superstore	These are free-standing facilities that specialize in the sale of home improvement merchandise.	862
Regional Shopping Center	A shopping center is an integrated group of commercial establishments that is planned, developed, owned and managed as a unit. A shopping center's composition is related to its market area in terms of size, location and type of store.	820
Strip Mall	Small strip shopping centers contain a variety of retail shops and specialize in quality apparel, hard goods and services such as real estate offices, dance studios, florists and small restaurants.	826

Table 1: Land Use Subtype Descriptions

Land Use Subtype	Description[1]	ITE Number
Supermarket	Supermarkets are free-standing retail stores selling a complete assortment of food: food preparation and wrapping materials; and household, cleaning items. Supermarkets may also contain the following products and services: ATMs, automobile supplies, bakeries, books and magazines, dry cleaning, floral arrangements, greeting cards, limited-service banks, photo centers, pharmacies and video rental areas.	850
COMMERCIAL		
Bank (With Drive-Through)	Drive-in banks provide banking facilities for motorists who conduct financial transactions from their vehicles; many also serve patrons who walk into the building.	912
General Office Building	A general office building houses multiple tenants where affairs of businesses commercial or industrial organizations or professional persons or firms are conducted. If information is known about individual buildings, it is suggested that this land use be used instead of the more generic office park.	710
Government (Civic Center)	A group of government buildings that are interconnected by pedestrian walkways.	733
Government Office Building	This is an individual building containing either the entire function or simply one agency of a city, county, state, federal, or other governmental unit.	730
Hospital	A hospital is any institution where medical or surgical care and overnight accommodations are provided to non-ambulatory and ambulatory patients. However, it does not refer to medical clinics or nursing homes.	610
Medical Office Building	This is a facility that provides diagnoses and outpatient care on a routine basis but is unable to provide prolonged in-house medical and surgical care. One or more private physicians or dentists generally operate this type of facility.	720
Office Park	Office parks are usually suburban subdivisions or planned unit developments containing general office buildings and support services, such as banks, restaurants and service stations, arranged in a park-or campus-like atmosphere. This should be used if details on individual buildings are not available.	750
Pharmacy/Drugstore W/O Drive Thru	These are retail facilities that primarily sell prescription and non-prescription drugs. These facilities may also sell cosmetics, toiletries, medications, stationery, personal care products, limited food products and general merchandise. The drug stores in this category do not contain drive-through windows.	880

Table 1: Land Use Subtype Descriptions

Land Use Subtype	Description[1]	ITE Number
Pharmacy/Drugstore With Drive Thru	These are retail facilities that primarily sell prescription and non-prescription drugs. These facilities may also sell cosmetics, toiletries, medications, stationery, personal care products, limited food products and general merchandise. The drug stores in this category contain drive-through windows.	881
Research & Development	R&D centers are facilities devoted almost exclusively to R&D activities. The range of specific types of businesses contained in this land use category varies significantly. R&D centers may contain offices and light fabrication areas.	760
INDUSTRIAL		
General Heavy Industry	Heavy industrial facilities usually have a high number of employees per industrial plant and are generally limited to the manufacturing of large items.	120
General Light Industry	Light industrial facilities are free-standing facilities devoted to a single use. The facilities have an emphasis on activities other than manufacturing and typically have minimal office space. Typical light industrial activities include printing, material testing and assembly of data processing equipment.	110
Industrial Park	Industrial parks contain a number of industrial or related facilities. They are characterized by a mix of manufacturing, service and warehouse facilities with a wide variation in the proportion of each type of use from one location to another. Many industrial parks contain highly diversified facilities.	130
Manufacturing	Manufacturing facilities are areas where the primary activity is the conversion of raw materials or parts into finished products. It generally also has office, warehouse, and R&D functions at the site.	140
Refrigerated Warehouse-No Rail	This is a warehouse that has refrigeration but no rail spur.	152
Refrigerated Warehouse-Rail	This is a warehouse that has refrigeration and a rail spur.	152
Unrefrigerated Warehouse-No Rail	This is a warehouse that does not have refrigeration and no rail spur.	152
Unrefrigerated Warehouse-Rail	This is a warehouse that does not have refrigeration but has a rail spur.	152

1. Based on land use descriptions in Institute of Transportation Engineers (ITE) Trip Generation Manual, 9th Edition.

Unit Amount and Size Metric

By tabbing over to the Unit Amount and Size Metric columns, respectively, the user can enter the number of units (e.g., houses, apartments, etc.) and the corresponding size metric (e.g., per

1000 sq ft, employees, students, etc.). This data combination will be used to populate the lot acreage, square feet and population columns on this screen. For example, a school land use allows the user to define its size by the number of students, building square footage, or number of employees. It is important to note that the square footage, which is used for calculating such impacts as architectural coatings and energy use, relates to the total building square footage and not the building footprint or lot acreage which is used for housing density as well as grading and site preparation calculations.

Lot Acreage

If actual lot acreage data is available, the user should override the default value. However, for a mixed use, multi-story building, the user should not override the square footage default value for each individual land use or the acreage default value assigned to the residential portion or the split between the non-residential land uses if there is no residential portion. The figure below provides an example of a mixed use project and instructions for applying the appropriate square footage and acreage.

Acreage is used to estimate housing density and assign construction default data (e.g., grading, site preparation, etc.). Table 2 contains housing density default data per land use in terms of dwelling units (DU) per acre. By using this data, CalEEMod can estimate the number of acres per dwelling unit (DU) for residential land use. For example, if the user enters 10 apartments in a low rise building, then the lot acreage will be 0.625 acre (10 DU divided by 16 acres/DU). According to the California Energy Commission's Residential Appliance Saturation Survey (RASS), the metric for low rise apartments is 1,000 square feet per DU (see Table 2.1). Similarly, using the same example, the building footprint will be 0.23 acre (10 DU x 1000 sq ft/DU x 1 acre/43,560 sq ft). Thus, the total lot acreage includes the residential footprint plus driveway and landscaping/open space.

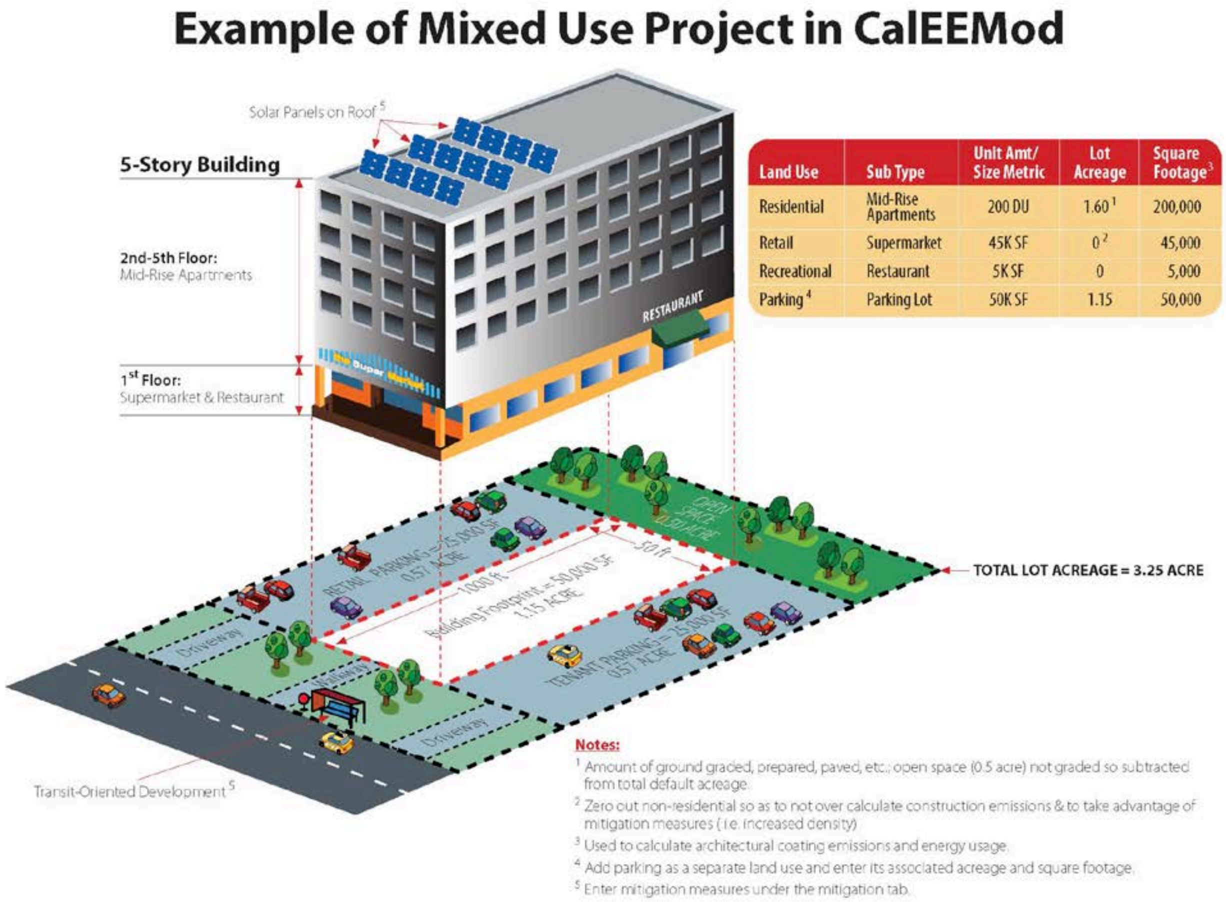


Table 2: Default Housing Density

Land Use Subtype	Density (Dwelling Units/Acre)
Single Family Housing	3
Apartments low rise	16
Apartments mid rise	38
Apartments high rise	62
Condo/townhouse	16
Condo/townhouse high rise	64
Mobile Home Park	8
Retirement Community	5
Congregate care (Assisted Living)	16

1. Based on the density assumed in ITE Trip Generation 8th Edition

After the user has completed entering all of land uses for the project, CalEEMod will add the lot acreage values for each land use and the total will be reflected in the lot acreage text box located at the bottom of the screen. The value in the total lot acreage box cannot be modified by the user.

Square Footage

If actual square footage of the total building or building footprint is known, the user should override the default value.

Population

After the completing the tabs for unit amount, size metric, lot acreage, and square footage, the population field will contain a default which represents an estimate of the population for each land use type and subtype selected by the user. If the actual population data is known, the user should override the default value.

After the user has completed entering all of land uses for the project, CalEEMod will add the population values for each land use and the total will be reflected in the population text box located at the bottom of the screen. The value in the total population box cannot be modified by the user.

City Park/Golf Course Building Area Square Feet (text box)

If the user selects a City Park and/or Golf Course land use, a text box will appear at the bottom of the screen that will prompt the user to enter the building square footage of all the buildings that will be located on the City Park and/or Golf Course property (e.g., restrooms/changing rooms, pro-shop, etc.). The user must input site-specific building square footage data because there are no default values for building footprints on these types of land uses. If the building square footage is left blank (e.g., zero square feet), a warning message will appear to remind the user to enter a value in this field.

Recreational Swimming Pool Building Area Square Feet (text box)

If the user selects a Recreational Swimming Pool land use, a text box will appear at the bottom of the screen that will prompt the user to enter the building square footage of all the buildings that will be located on the property (e.g., restrooms/changing rooms, pro-shop, etc.). The user must input site-specific building square footage data because there is no default value for the building footprint on this type of land use. If the building square footage is left blank (e.g., zero square feet), a warning message appear to remind the user to enter a value in this field.

4.3 Construction

After completing the Land Use screen and clicking on the Next button, the Construction screen will appear along with seven tabs/sub-screens that cover the following construction topic areas: Construction Phase; Off-Road Equipment; Dust from Material Movement; Demolition; Trips and VMT, On-Road Fugitive Dust, and Architectural Coatings. To move from one tab/subscreen to another, the user can use the Next and Previous buttons, or click on any of grey tabs. The construction tabs/sub-screens contain default information that was obtained from a survey of construction sites conducted by South Coast Air Quality Management District (SCAQMD). The construction survey data is grouped by construction phase and lot acreage and can be found in Appendix E1. The default construction equipment list and phase length data were determined to be the most appropriate for the size and types surveyed. In addition, some data in the survey was extrapolated to create default values for project sizes that were not in the survey. However, if the user has more detailed site-specific equipment and phase information, the user should override the default values.

4.3.1 Construction Phase

The Construction Phase tab is where the user can enter the type of each construction phase and the date range for each phase. . Default phases are based on the total lot acreage of the project. Depending on the project being modeled, not all phases may be necessary so the user may need to delete phases that are not applicable to the project. For example, not all projects require demolition. In addition, the user may need to add multiple phases of similar types for large projects with staged build out scenarios. It is important to note that if a project has demolition, grading, and site preparation phases, the user will need to provide additional project-specific data on the Demolition and Dust from Material Movement sub-screens.

Phase Name and Phase Type

The Phase Name and Phase Type fields will be automatically populated with the following default construction phases: Site Preparation; Demolition; Grading; Building Construction; Paving; and, Architectural Coating. The inclusion of any of these phases will define the types of calculations and default assumptions for on-road vehicle trips and fugitive emissions that occur in subsequent construction sub-screens. The definitions of the default phase types are as follows:

- *Demolition* involves removing buildings or structures.
- *Site Preparation* involves clearing vegetation (grubbing and tree/stump removal) and removing stones and other unwanted material or debris prior to grading.
- *Grading* involves the cut and fill of land to ensure that the proper base and slope is created for the foundation.
- *Building Construction* involves the construction of the foundation, structures and buildings.
- *Architectural Coating* involves the application of coatings to both the interior and exterior of buildings or structures, the painting of parking lot or parking garage striping, associated signage and curbs, and the painting of the walls or other components such as stair railings inside parking structures.
- *Paving* involves the laying of concrete or asphalt such as in parking lots, roads, driveways, or sidewalks.

Start Date and End Date

The user can enter with the aid of a calendar, the Start Date and End Dates for each construction phase. The default Start Date is the Start of Construction date defined on the Project Characteristics screen. The cells will be automatically populated with a default construction schedule starting with the Demolition phase, with subsequent phases starting the following day after the previous phase's end date. The user may change the defaults to alter the total days estimated for each phase. Because CARB's emission factors vary from year to year, when the user inserts the start and end dates for each construction phase, the model will select the correct emission factors for the year when each piece of off-road equipment will be utilized.

Days per Week

The user can select from a drop down box the number of days per week (either 5, 6, or 7 days) that construction will occur. Five days per week assumes that construction will occur from Monday through Friday, and six days per week assumes that construction will occur Monday through Saturday.

Total Days

The Total Days field is intended to indicate the number of days that it will take to complete a particular construction phase and this field is initially populated with default values. If the End Date or the Days per Week fields are changed, clicking the Total Days field will trigger a recalculation of the Total Days. If the Total Days field for any phase is changed, then once leaving this field, the program will automatically adjust the End Date based on the Start Date for that phase.

4.3.2 Off-Road Equipment

The Off-Road Equipment tab is for the user to select the type and quantity of off-road equipment needed for each construction phase and to define the daily usage schedule. Since equipment lists can be lengthy and vary widely for each construction phase, the user will need to first select the phase from Phase Name drop down list or by clicking on the Previous or Next buttons located next to the phase name, and then select the off-road equipment that will be used for each construction phase. The Off-Road Equipment screen calculates emissions based on the expected off-road equipment engine use for each piece of equipment listed over the duration of the phase length. It is important to note that fugitive emissions from off-road equipment are calculated elsewhere on other construction screens.

After the user enters the Equipment Type, Number of Units, and Hours per Day for each piece of equipment that will be used in any phase, The Horsepower and Load Factor fields will be automatically populated with the default average values from CARB's OFFROAD2011., If equipment-specific information is available, the user can override these default values. In some cases, CARB's OFFROAD2011 emission factors are not available for all years. Thus, if the user selects a construction year that does not have corresponding emission factors, CalEEMod has been programmed to substitute the emissions factors from nearest, lower end (e.g., oldest) year. For example, if construction will occur in year 2037 (a year which does not have emission factors), CalEEMod will substitute the emission factors from year 2035 instead. Since newer equipment tends to have less emissions than older equipment, by selecting emission factors from year 2035 (an older year), the calculations may result in a conservative, slight overestimate of emissions.

If the project requires the use of off-road equipment that is not specifically listed in the drop down list, the user can select from three generalized equipment categories to add customized equipment to the analysis: 1) Other Construction Equipment; 2) Other General Industrial Equipment; and, 3) Other Material Handling Equipment. In addition, the user may choose to select a surrogate equipment type which has a similar horsepower rating and load factor. To include water trucks and cement trucks in the analysis, the user needs to first determine if these trucks are off-road or on-road vehicles. If they are only driven off-road, then the user can select the Off-Highway Trucks category in the Off-Road Equipment screen. If the trucks are driven on-road, the user can account for the on-road emissions by entering this information as Additional Vendor Trips on the Trips and VMT screen (see Subchapter 4.3.5).

4.3.3 Dust from Material Movement

The Dust from Material Movement sub-screen is intended for calculating fugitive dust emissions associated with the Site Preparation and Grading phases (defaults) during construction. This sub-screen calculates the following three types of fugitive dust: 1) fugitive dust from dozers moving dirt; 2) fugitive dust from graders or scrapers leveling the land; and; 3) fugitive dust from loading or unloading dirt into haul trucks. These methods have been adapted from USEPA's AP-42 method for Western Coal Mining. Once the enters the amount of material imported and exported to the site, CalEEMod will estimate the number of hauling trips associated with from material transport activities. The user may define the units in terms of Ton of Debris or Cubic Yards. The user may also select whether the import/export of material is phased (e.g., a the same truck that arrives with material departs with another load of material to export in one round trip or two-one way trips. The calculations for non-phased material import/export trips assume that one truck arrives empty and departs full and a different truck arrives full for a total of two round trips (or four one-way trips). Thus, phasing material import and export trips reduces the number of haul trips.

The Total Acres Graded field represents the cumulative distance traversed on the property by the grading equipment, assuming a blade width of 12 feet. In order to properly grade a piece of land, multiple passes with grading equipment may be required. So even though the lot size is a fixed number of acres, the Total Acres Graded could be an order of magnitude higher than the footprint of the lot and is calculated based on the equipment list (including number of equipment), the number of days need to complete the grading and/or site preparation phase, and the maximum number of acres a given piece of equipment can traverse in an 8-hour workday. For more information regarding how Dust from Material Movement is calculated, including grading rates, see Appendix A, Subchapter 4.3.

4.3.4 Demolition

The Demolition sub-screen is intended for the user to enter the amount of material that is demolished, if a demolition phase is selected by the user as part of the construction project.

The user can select the Size Metric to define the amount of demolished material that is expected to be generated during the demolition phase in terms of Ton of Debris or Building Square Footage. With this data, fugitive dust emissions generated during demolition are calculated. The calculation of fugitive dust emissions during demolition is derived from the methodology described in the report prepared for the USEPA by Midwest Research Institute, Gap Filling PM_{10} Emission Factors for Selected Open Area Dust Sources.

4.3.5 Trip and VMT

The Trip and VMT sub-screen is used to provide the number and length (in terms of vehicle miles traveled or VMT) of on-road vehicle trips for workers, vendors, and hauling for each construction phase. Depending on the land use type and subtype combined with the various construction phases, CalEEMod will populate the fields for Number of Trips, Trip Length, and Vehicle Class for worker, vendor and haul trips, respectively, with default values. The vehicle class descriptor HHDT, MHDT means that there is a 50/50 percent mix of heavy-heavy duty trucks and medium-heavy duty trucks. Similarly, the vehicle class descriptor LDA, LDT1, LDT2 means that there is a 50/25/25 percent mix of light duty autos, light duty truck class 1 and light duty truck class 2, respectively. The user may override the defaults and enter different weightings of vehicle fleet mixes. It is important to note that if the user selects a construction year that does not have corresponding EMFAC2014 emission factors for on-road vehicles, CalEEMod has been programmed to substitute the emissions factors from nearest, lower end (e.g., oldest) year. For example, if construction will occur in year 2037 (a year which does not have emission factors), CalEEMod will substitute the emission factors from year 2035 instead. Since newer equipment tends to have less emissions than older equipment, by selecting emission factors from year 2035 (an older year), the calculations may result in a conservative, slight overestimate of emissions.

CalEEMod quantifies the number of construction workers by multiplying 1.25 times the number of pieces of equipment for all phases (except Building Construction and Architectural Coating). For the Building Construction, the number of workers is derived from a study conducted by the Sacramento Metropolitan Air Quality Management District (SMAQMD) which determined the number of workers needed for various types of land uses and corresponding project size. This study and its analysis are included in Appendix E2. For the Architectural Coating phase, the number of workers is approximately 20% of the number of workers needed during the Building Construction phase.

The number of vendor trips during the Building Construction phase is also derived from a study conducted by the SMAQMD. The SMAQMD trip survey during construction counted cement and water trucks as vendor trips (instead of counting them as off-road vehicle trips) and these trip rates were incorporated into the calculations for the Building Construction phase. If the user deletes the Building Construction phase from the analysis, but the project will require water and/or cement trucks, then the user will need to account for these either as vendor trips under another construction phase or under the Off-Road equipment screen.

The default values for hauling trips are based on the assumption that a truck can haul 20 tons (or 16 cubic yards) of material per load. If one load of material is delivered, CalEEMod assumes that one haul truck importing material will also have a return trip with an empty truck (e.g., 2 one-way trips). Similarly, a haul truck needed to export material is assumed to have an arrival trip in an empty truck and a loaded departure truck (e.g., 2 one-way trips). Thus, each trip to import and export material is considered as two separate round trips (or 4 one-way trips). However, if the Phase box is checked, the same haul truck that imported the material will be assumed to be the same haul truck that export material resulting in one round trip (or 2 one-way trips).

4.3.6 On-Road Fugitive Dust

The On-Road Fugitive Dust sub-screen defines the variables that will be used to determine the fugitive dust emissions from on-road vehicles driving over paved and unpaved roads during construction. CalEEMod automatically populates the data fields based on the construction phase. The calculations use emission factors from USEPA's AP-42 for paved roads (January 2011 edition) and unpaved roads (November 2006 edition). Each data field is the same as those defined in the aforementioned AP-42 sections.

4.3.7 Architectural Coatings

The Architectural Coatings sub-screen is intended to calculate ROG emissions associated with painting the interior/exterior of residential and non-residential buildings as well as calculate emissions from parking lot painting or striping. The user may override any of the default interior and exterior surface areas estimated for residential and non-residential buildings. In addition, each of these surface types has a different emission factor indicating the ROG content of the paint in grams per liter (g/L). It is important to note that the parking area square footage is not included in the non-residential interior/exterior square footage when calculating emissions attributable to parking lot striping. See Appendix A, Subchapter 4.7 for the methodology of estimating surface areas to be coated from building square footage.

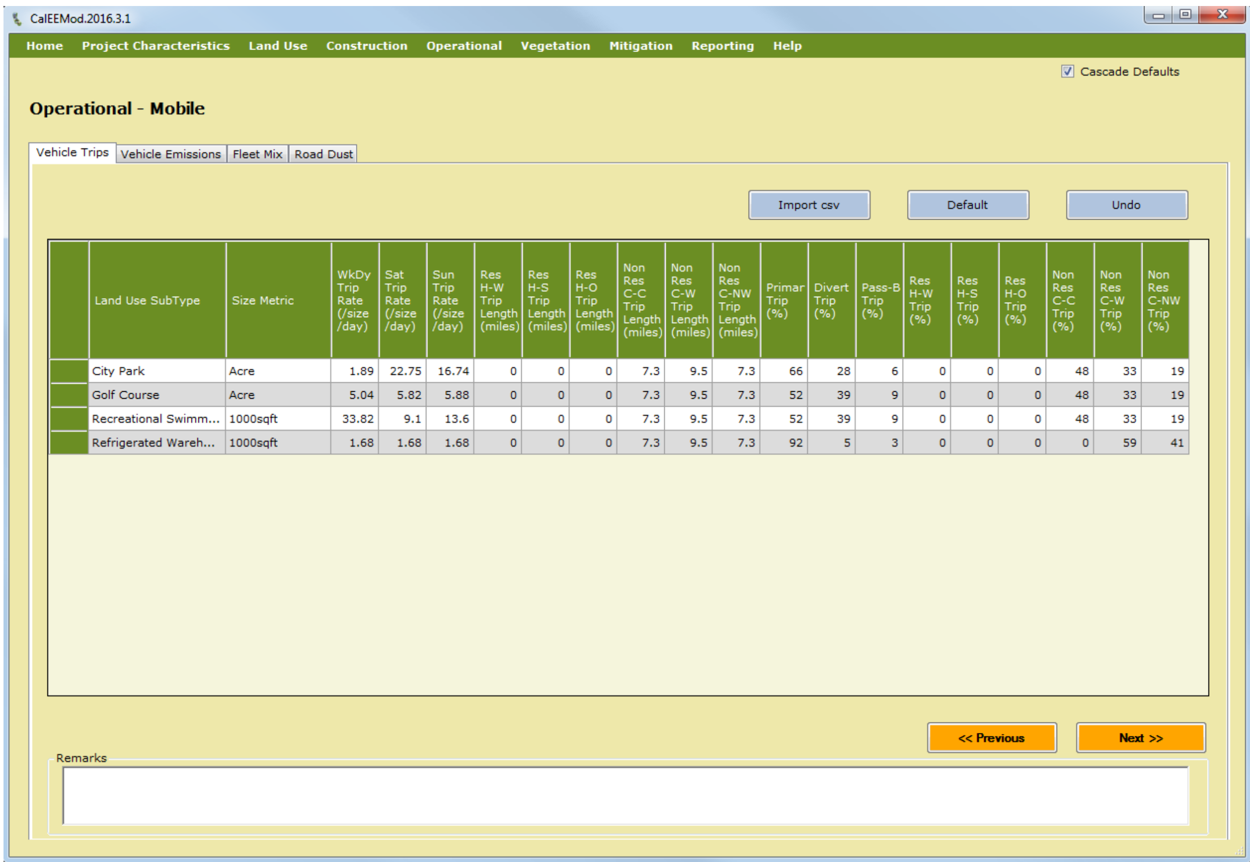
4.4 Operational Mobile

The operational mobile screen is made up of four sub-screens: Vehicle Trips, Vehicle Emissions, Fleet Mix and Road Dust. These screens are used in defining the information necessary to calculate the emissions associated with operational on-road vehicles.

4.4.1 Vehicle Trips

This sub-screen includes the trip rates, trip lengths, trip purpose, and trip type percentages for each land use subtype in the project. The user can edit any of this information by entering a new value in the appropriate cell. Trip rates are in terms of the size metric (thousand square footage or dwelling unit) defined on the land use screen and are listed for weekday, Saturday and Sunday if available. Trip lengths are for primary trips. Trip purposes are primary, diverted, and pass-by trips. Diverted trips are assumed to take a slightly different path than a primary trip and are assumed to be 25% of the primary trip lengths. Pass-by trips are assumed to be 0.1 miles in length and are a result of no diversion from the primary route. Residential trip types are defined as home-work (H-W), home-shop (H-S), and home-other (H-O). Non-residential trip types are defined as commercial –customer (C-C), commercial-work (C-W), and commercial-nonwork (C-NW) such as delivery trips. Appendix A includes the equations and methodology used to calculate motor vehicle emissions from the operation of a project.

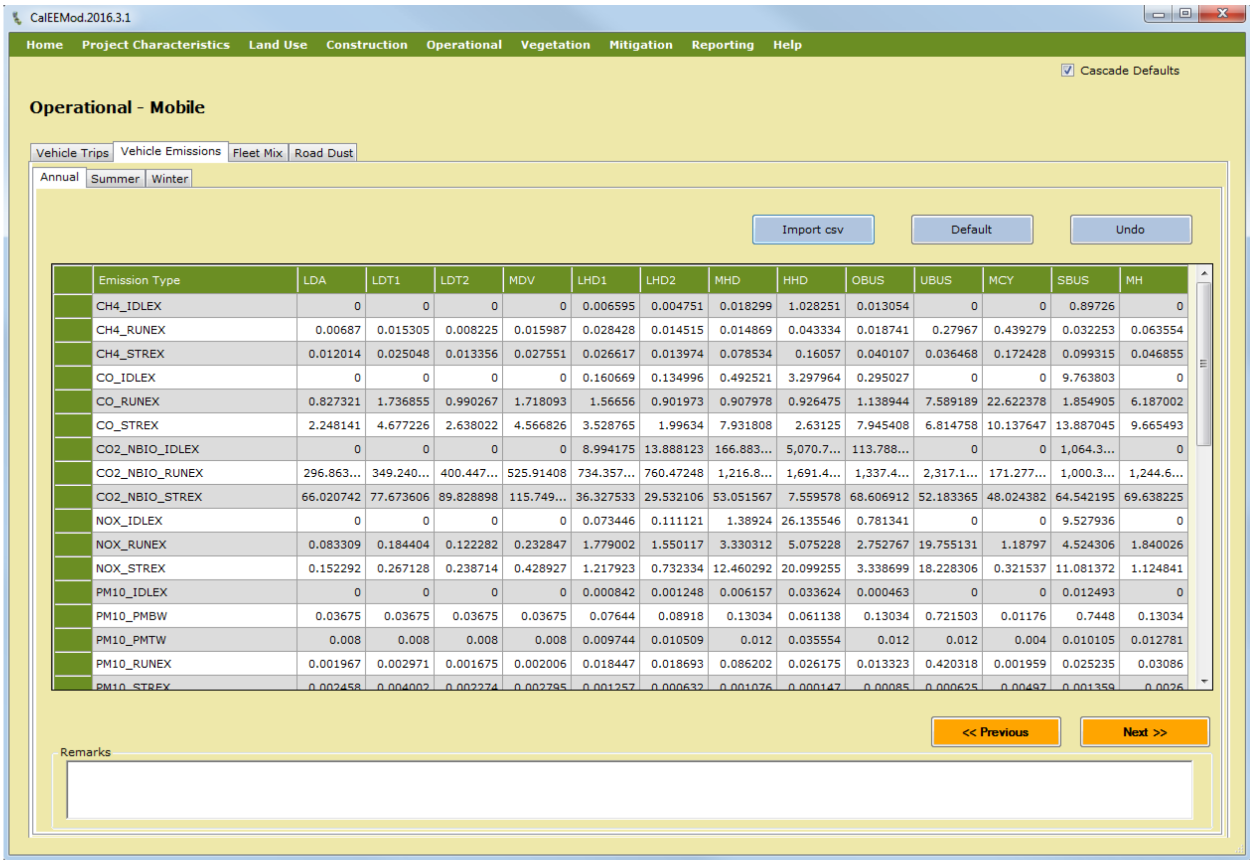
The trip rates are based on ITE 9th edition average trip rates for the respective land use categories.



4.4.2 Vehicle Emissions

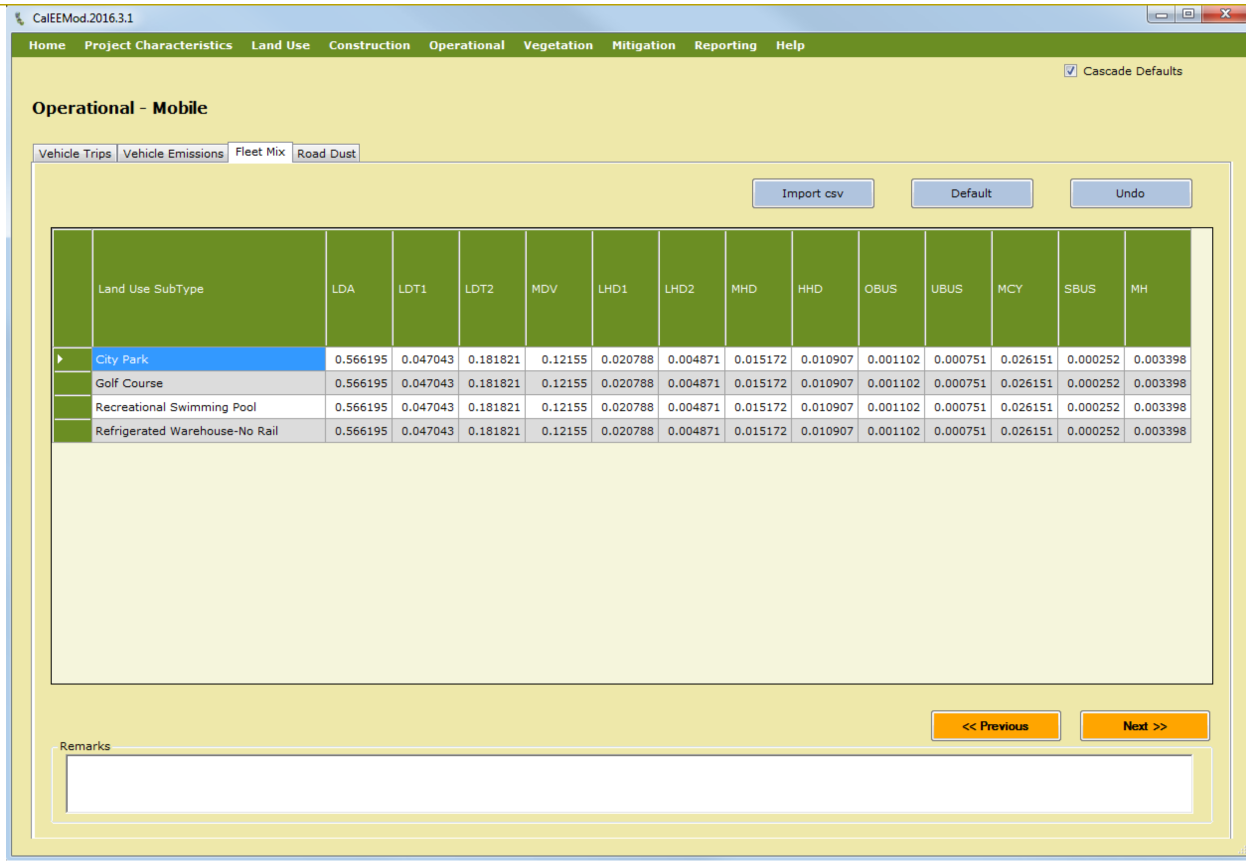
This sub-screen contains the detailed vehicle emission factors based on EMFAC2014. Appendix A includes the description of how these emission factors were derived from EMFAC2014. It is anticipated that most users will not edit data in this sub-screen. There are separate tabs for annual, summer, and winter emissions values. If the user wants to alter the breakdown of fuel types (catalytic, non-catalytic, and other) within a vehicle class, they will have to provide their own data. This will likely be an infrequent change due to CEQA enforceability requirements.

This screen along with the previous screen (Vehicle Trips) and next screen (Fleet Mix) will provide the data for the model to calculate the emissions associated with on-road motor vehicle use. The calculation does not include the fugitive dust emissions from travel over roads as these are associated with the next screen (Road Dust).



4.4.3 Fleet Mix

CalEEMod Version 2016.3.1 separates the fleet mix from the Vehicle Emissions screen and creates a Fleet Mix screen so that users are able to change default fleet mix associated with different land use subtypes.



4.4.4 Road Dust

This sub-screen is used to change any of the default values that are used in the USEPA's AP-42 methods for calculating fugitive emissions from paved and unpaved roads. The defaults for the road dust (e.g., material silt content, material moisture content, and mean vehicle speed) are statewide averages, but the user has the ability to override the defaults if data specific to the project is known. Local jurisdictions can also provide guidance to users as to what default properly reflects known regional road dust parameters.

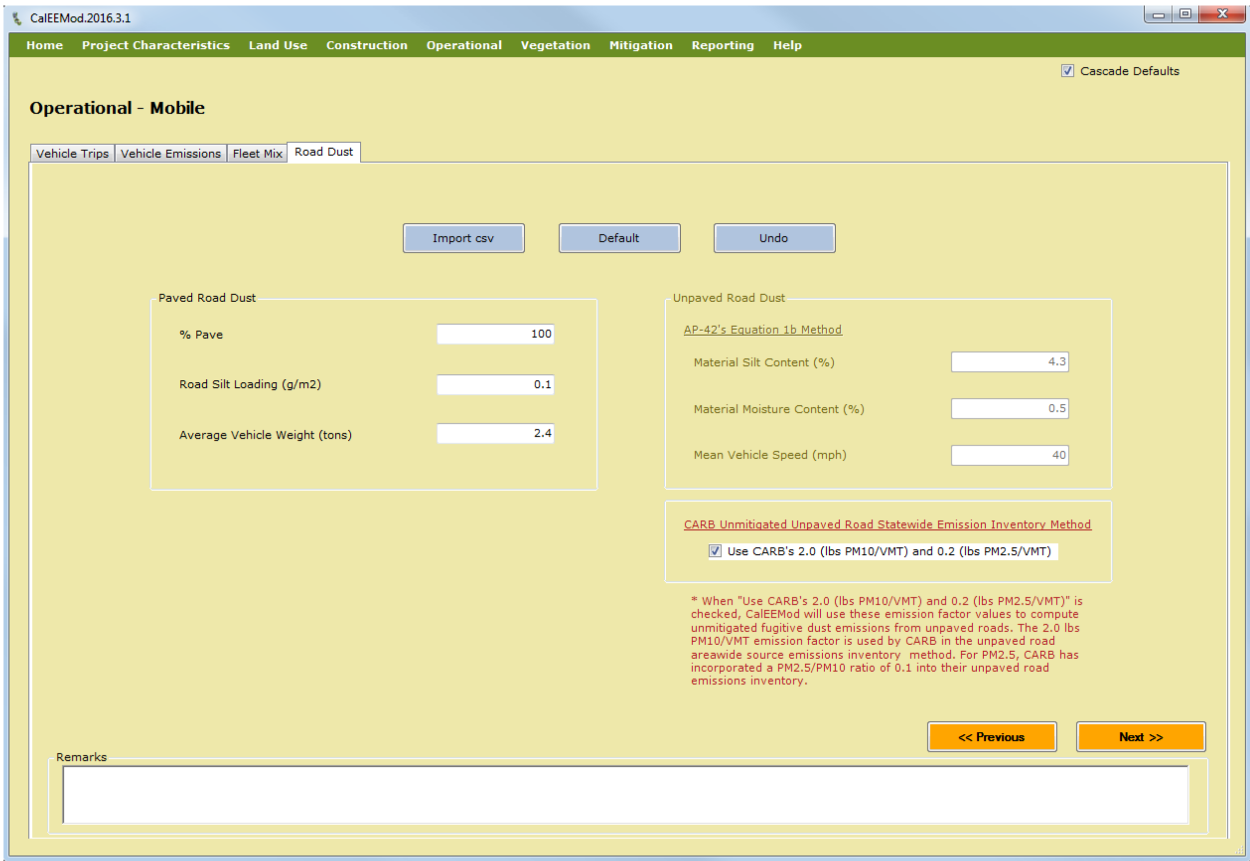
For the San Luis Obispo region, the user is recommended to provide the following unpaved road dust parameters overriding the statewide defaults if users choose to use USEPA's AP-42 methods:

9.3 for Material Silt Content (%) *(instead of 4.3 statewide default)*

0.1 for Material Moisture Content (%) *(instead of 0.5 statewide default)*

32.4 for Mean Vehicle Speed (mph) *(instead of 40 statewide default)*

For San Luis Obispo County APCD and Sacramento Metropolitan AQMD, the user has a new default option in CalEEMod Version 2016.3.1 to use CARB's 2.0 lbs PM_{10}/VMT[9] as the unmitigated fugitive dust emission factor for unpaved roads during the operational phase. An emission factor of 0.2 lbs $PM_{2.5}$/VMT is applied based on a 10% $PM_{2.5}$/ PM_{10} ratio[10, 11]. By checking the box, the program will use CARB's emission factor to override the calculated emission factor based on USEPA AP-42. Note: For project locations other than San Luis Obispo County APCD and Sacramento Metropolitan AQMD, CARB's 2.0 lbs PM_{10}/VMT is not a selection option.



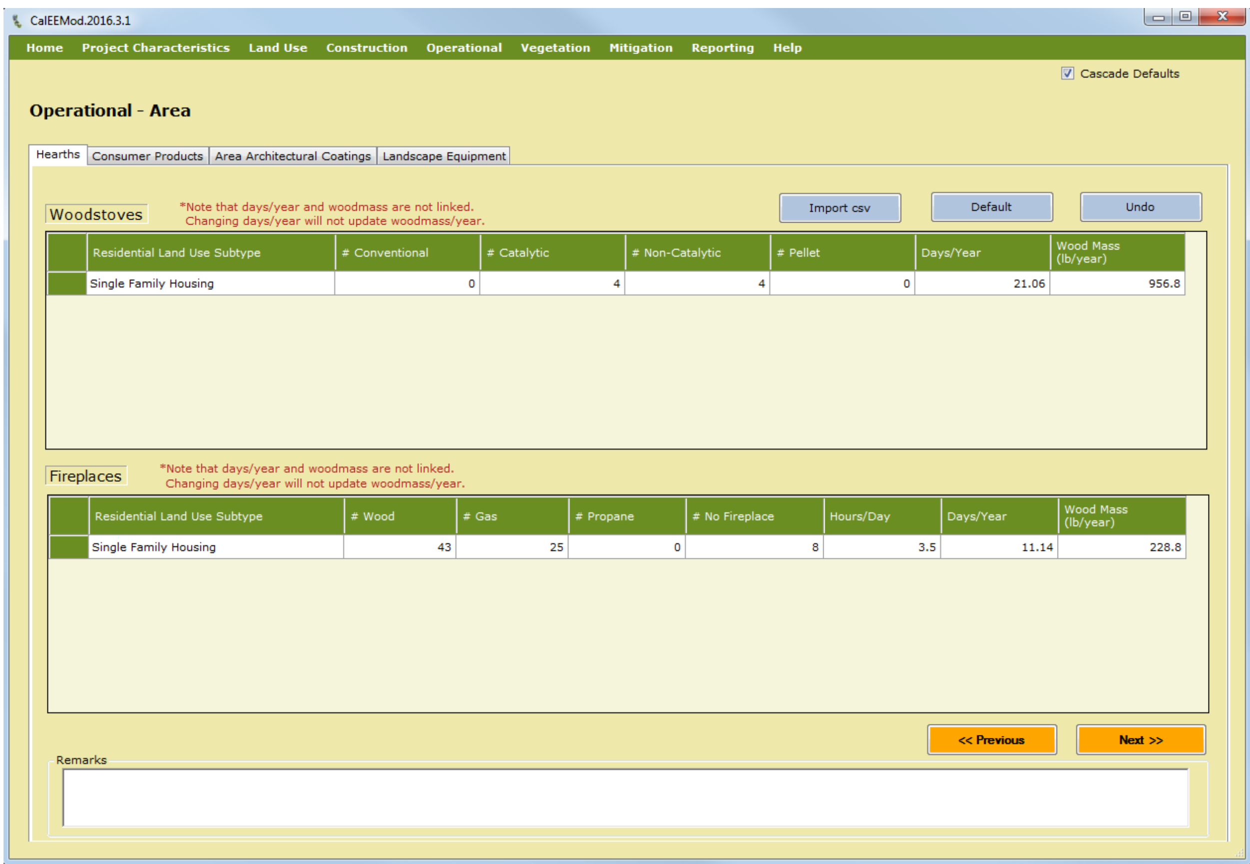
4.5 Area

The area source screen consists of four sub-screens: Hearths, Consumer Products, Area Architectural Coatings, and Landscaping Equipment. Natural gas emission variables from all uses except hearths are included in the energy use screen (described in Section 4.6).

9 Available at: http://www.arb.ca.gov/ei/areasrc/fullpdf/full7-10.pdf
10 Available at: http://www3.epa.gov/ttnchie1/ap42/ch13/related/mri_final_fine_fraction_dust_report.pdf
11 Available at: http://www.arb.ca.gov/app/emsinv/emssumcat_query.php?F_YR=2015&F_DIV=-4&F_SEASON=A&SP=2009&F_AREA=CA#0

4.5.1 Hearths and Woodstoves

This sub-screen allows the user to enter the number of woodstoves and hearths of various types as well as the usage of these devices. Woodstoves are separate from fireplaces since a home may have both and these devices may have different use patterns. The number of devices that is entered for each device type represents the total number of devices installed in the dwelling units for a particular land use. Appendix A contains the emissions calculation methodology and details of variables that the user cannot override. Some of these emissions may be classified as biogenic and are therefore reported as CO_2-Biogenic. For most locations a default percent of hearths and stoves was provided by air districts and is multiplied through. The number of devices was chosen to include in CalEEMod instead of a percentage to allow for incorporation of various air district rules regarding hearths and woodstoves in new residences without having specialized data entry screens. Commercial land uses by default do not have hearths or woodstoves in CalEEMod. These are included for those cases where they may occur such as in restaurants or hotels.



The San Joaquin Valley jurisdiction has a regulatory limit on the number of hearths depending upon the type and number of residential development. The regulatory limit is generated by CalEEMod but all the input parameters (e.g., unit density, etc.) are necessary to determine the value. Thus, the regulatory limit is disclosed during the reporting stage under the Default Value box in the report. The model, however, calculates emission impacts from the number of hearths inputted on the Area source screen (listed under the New Value column in the report). Therefore, if the user wants to calculate emissions from regulatory limit, the report needs to be run to determine the regulatory limit and the user needs to go back to the Area Source screen to input that value and re-run the report. If the user chooses to calculate emissions from a different number of hearths (e.g., a number of hearths less than the regulatory limit), then that number needs to be inputted on the Area Source screen to properly calculate emissions. Again, the report will provide the regulatory limit under the Default Value column and the user input value under New Value column.

4.5.2 Consumer Products

Consumer products are various solvents used in non-industrial applications which emit ROGs during their product use. These typically include cleaning supplies, kitchen aerosols, cosmetics and toiletries. SCAQMD has developed an emission factor based on the total of all building square footage for both residential and non-residential buildings. Details of how this emission factor was developed can be found in Appendix E. The user can change this emission factor if they have more relevant data. CalEEMod Version 2016.3.1 separates ROG emissions from pesticides/fertilizers for City Parks and Golf Courses and ROG emissions from parking surface degreasers from the general category consumer products. CalEEMod Version 2016.3.1 also assumes that there would be no ROG emissions from the actual pool surface area for Recreational Swimming Pools because the chemicals used for maintaining pools are not considered to be ROGs. Details of how the ROG emission factors for pesticides/fertilizers and parking surface degreasers were determined can be found in Appendix E.

4.5.3 Area Architectural Coatings

This sub-screen has text boxes for the reapplication rate and coating ROG content for each building surface type and parking surface. The reapplication rate is the percentage of the total surface area that is repainted each year. A default of 10% is used, meaning that 10% of the surface area is repainted each year (i.e., all surface areas are repainted once every 10 years). Daily emissions divide the annual rate by 365 days per year. This is based on assumptions used by SCAQMD in their district rules regarding architectural coatings. Some districts provided details on their coating regulations that phase-in over time, which have been incorporated to the extent feasible, given the general classifications of paint (interior or exterior for residential and non-residential). Coating ROG content from state regulations are used for air districts that did not provide specific architectural coating information. Consult your local air district for suggested values that may be lower than the state regulations.

The ROG contents under the Operational Area Architectural Coatings screen (either CalEEMod defaults or site-specific values defined by users) become the default ROG contents for the Area Mitigation screen. The user may check the box under the Area Mitigation screen and specify a lower ROG content limit.

4.5.4 Landscape Equipment

This sub-screen has two text boxes to show the number of snow days or summer days. In addition, the defaults consider a realistic number of days which the landscaping equipment would be operated. For example, landscaping at commercial facilities typically do not take place during a weekend or during the summer at educational facilities that are not open. The number of days are applied to the appropriate landscape equipment types available in OFFROAD2011 using the average horsepower and load factors of the population mode. The derivation of emission factors used for each equipment type from OFFROAD2011 is described in Appendix A.

4.6 Energy Use

The energy use screen is used to gather the information necessary to estimate the emissions associated with building electricity and natural gas usage (non-hearth). The electricity energy use is in units of kilowatt hours (kWh) per size metric for each land use subtype. Natural gas use is in units of a thousand British Thermal Units (kBTU) per size metric for each land use subtype.

Title 24 of the California Code of Regulations, known as the California Building Standards Code or Title 24, contains energy conservation standards applicable to all residential and non-residential buildings throughout California. With CalEEMod, building electricity and natural gas use is divided into two categories: 1) end uses subject to Title 24 standards; and, 2) end uses not subject to Title 24 standards. The distinction is used when the mitigation measure for exceeding Title 24 standards (BE-1) is applied. Lighting is also a separate category in CalEEMod for which a separate mitigation measures (LUT-1) may be applied for using energy efficient lighting.

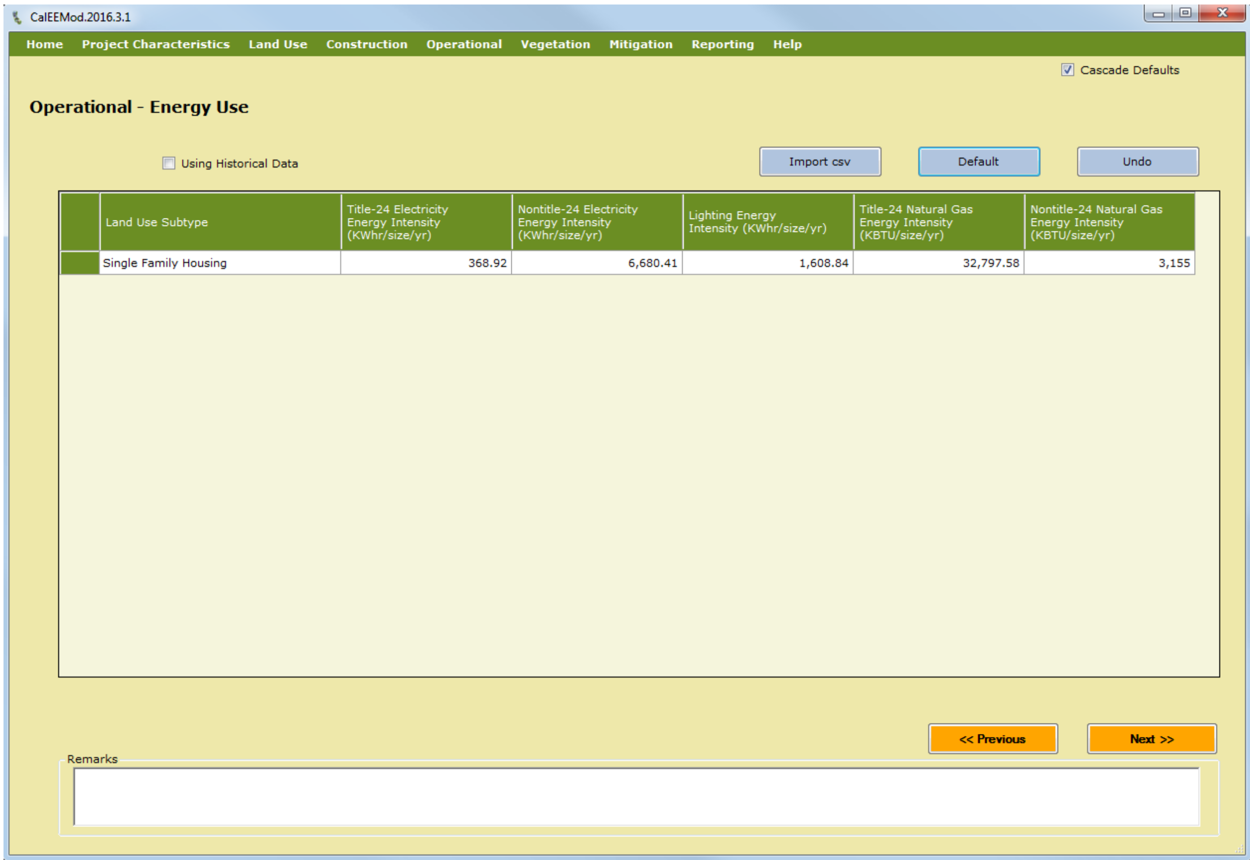
For electricity, Title 24 uses include the major building envelope systems covered by Part 6 (California Energy Code) of Title 24 such as space heating, space cooling, water heating, and ventilation. Non-Title 24 uses include all other end uses, such as appliances, electronics, and other miscellaneous plug-in uses. Because some lighting is not considered as part of the building envelope energy budget, and since a separate mitigation measure is applicable to this end use, CalEEMod makes lighting a separate category.

For natural gas, uses are likewise categorized as Title 24 or Non-Title 24, with Title 24 uses including building heating and hot water end uses. Non-Title 24 natural gas uses include cooking and appliances (including pool/spa heaters).

The baseline values are based on the CEC sponsored California Commercial End Use Survey (CEUS) and Residential Appliance Saturation Survey (RASS) studies[12]. For climate zones not included in these surveys, data from the closest climate zone was used as a surrogate. Since these studies are based on older buildings, adjustments have been made to account for

12 CEC. October 2010. Residential Appliance Saturation Survey. Available at: http://www.energy.ca.gov/appliances/rass
CEC. March 2006. Commercial End-Use Survey. Available at: http://www.energy.ca.gov/ceus/

changes due to Title 24 building codes as described in Appendix E. The user should select the use historical box if they only want an adjustment to the 2005 standards which were in effect when CARB developed its Scoping Plan 2020 No Action Taken predictions. After selecting the historical button, the user must also click the default button to load the historical default values.



4.7 Water and Wastewater Use

This screen estimates the land uses contribution of GHG emissions associated with supplying and treating water and wastewater. This screen is used to enter the amount of water in gallons used indoors and outdoors for each land use subtype[13]. The indoor water is also used to

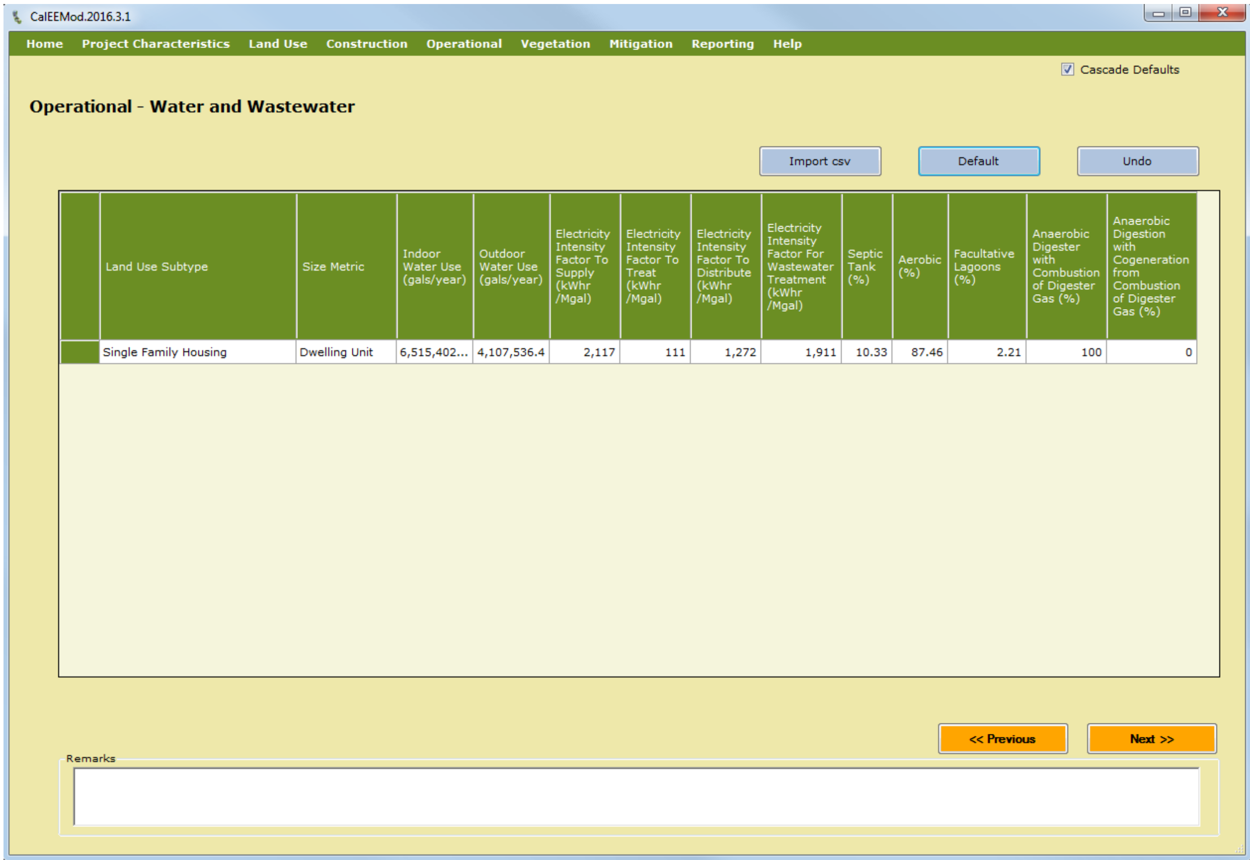
13 Gleick, P.H.; Haasz, D.; Henges-Jeck, C.; Srinivasan, V.; Cushing, K.K.; Mann, A. 2003. Waste Not, Want Not: The Potential for Urban Water Conservation in California. Published by the Pacific Institute for Studies in Development, Environment, and Security. Full report available at: http://www.pacinst.org/reports/urban_usage/waste_not_want_not_full_report.pdf. Appendices available at: http://pacinst.org/publication/waste-not-want-not/

Dziegielewski; B.; Kiefer, J.C.; Optiz, E.M.; Porter, G.A.; Lantz, G.L.; DeOreo, W.B.; Mayer, P.W.; Nelson, J.O. 2000. Commercial and Institutional End Uses of Water. Published by the American Water Works Association Research Foundation.

Northern California Golf Association. Improving California Golf Course Water Efficiency. Available at: http://www.water.ca.gov/wateruseefficiency/docs/2004Apps/2004-079.pdf estimate the amount of wastewater. The electricity intensity factor for various phases of providing water is provided. Depending on the specific water supply used or treatment method used these numbers can vary over a wide range. Supplying water is bringing the water from its primary source such as the ground, river, or snowpack to the treatment plant. Distributing the water is bringing the water from the treatment plant to the end users. The electricity intensity factors are multiplied by the utility GHG emissions intensity factors for the GHGs and are classified as indirect emissions. The default electricity intensity is from the CEC's 2006 Refining Estimates of Water-Related Energy Use in California using the average values for Northern and Southern California[14]. The location will automatically select the appropriate values if using these defaults. Since the electricity can vary greatly based on locations, the user should override these values if they have more specific information regarding their specific water supply and treatment.

Wastewater may also have direct emissions of GHGs. These depend on the type of wastewater treatment system (e.g., septic, aerobic or lagoons) used and therefore the wastewater treatment type percentages are variables. In addition, the model calculates impacts if the solids are digested either through an anaerobic digester or with co-generation from combustion of digester gas. Each type has associated GHG emission factors. Some of these may be classified as biogenic. Not all of the biogenic emissions are accounted for since there are not adequate emissions factors at this time. Refer to Appendix A on how to properly change the defaults, if necessary, and the methodology used to calculate impacts from wastewater treatment.

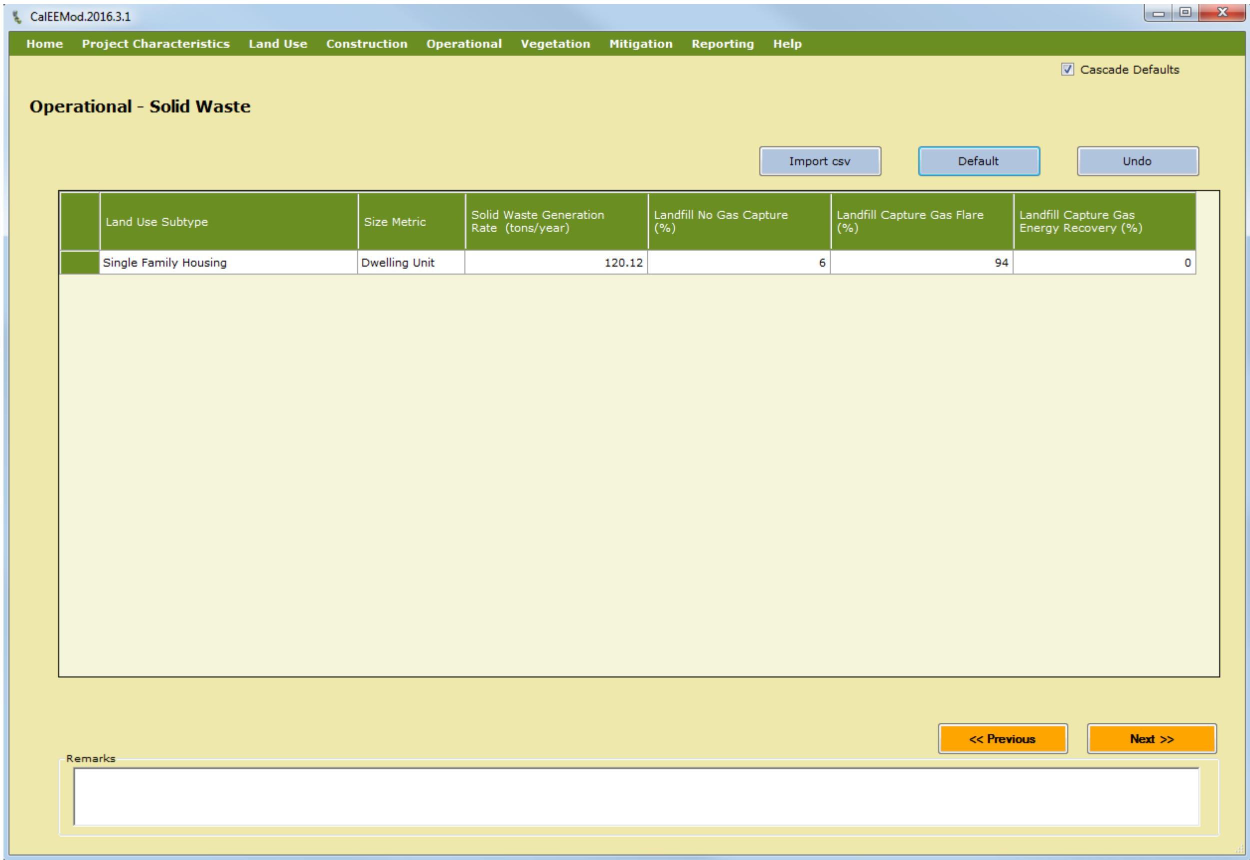
[14] CEC-500-2006-118. Available at http://www.energy.ca.gov/2006publications/CEC-500-2006-118/CEC-500-2006-118.PDF.



4.8 Solid Waste

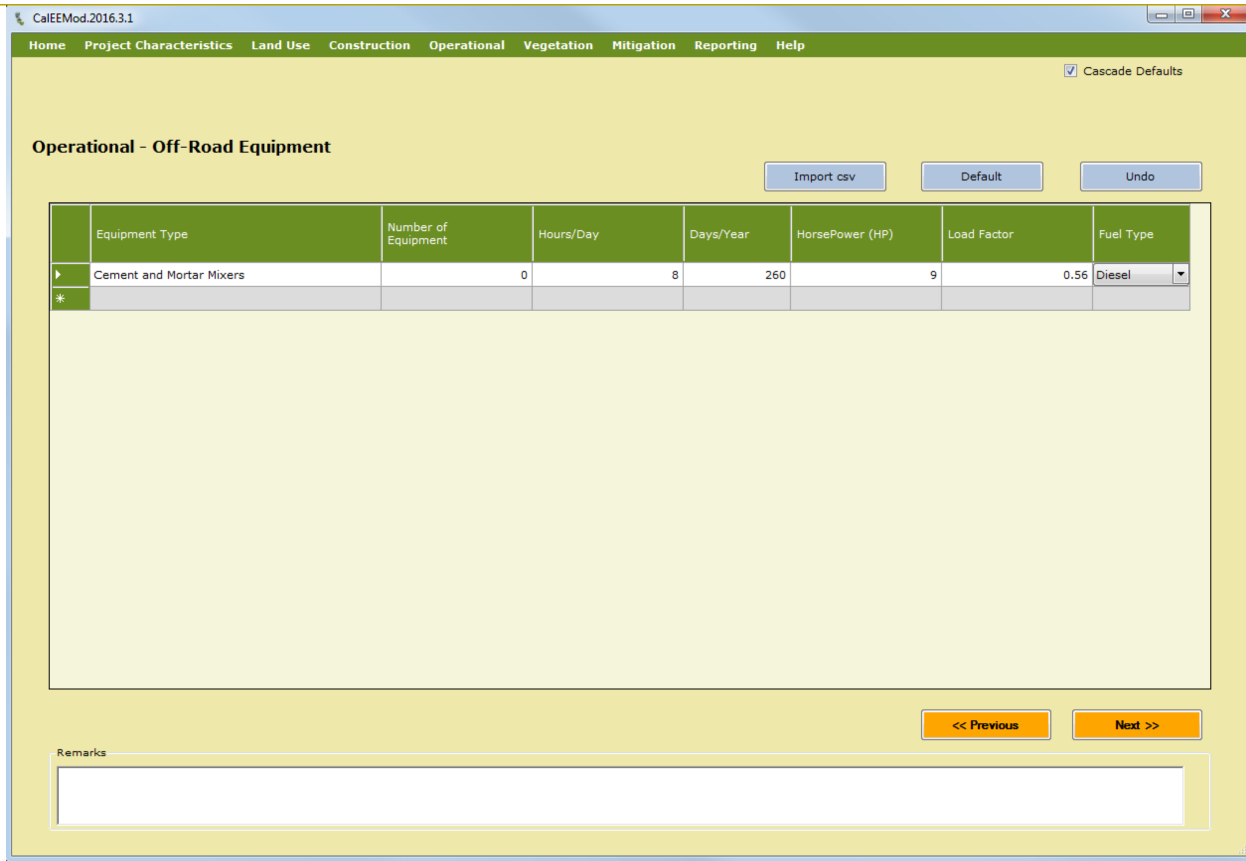
The solid waste screen determines the GHG emissions associated with disposal of solid waste into landfills. In order to estimate the eventual contribution of GHG emissions from solid waste disposed by a land use annually, the total amount of carbon dioxide and methane that would be evolved over the span of many years is calculated. This is based on the IPCC's methods for quantifying GHG emissions from solid waste using the degradable organic content of waste[15]. Waste disposal rates by land use and overall composition of municipal solid waste in California is primarily based on CalRecycle data. The amount of methane emitted depends on characteristics of the landfill, and therefore the default percentage is based on the types of landfills assumed by CARB in their GHG emissions inventories. Portions of these emissions are biogenic. The defaults for the gas capture (e.g., no capture, flaring, energy recovery) are statewide averages except for Santa Barbara APCD which has a 100% landfill capture gas flare. The user has the ability to override the defaults if the gas capture at the landfill to be used by the project is known. Local jurisdictions can also provide guidance to users as to what default properly reflects known regional solid waste gas capture.

15 IPCC. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 5 Waste. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html.



4.9 Off-Road Equipment

The Operational - Off-Road Equipment sub-screen allows the user to identify any off-road equipment used during operational activities (e.g., forklifts, cranes, loaders, generator sets, pumps, pressure washers, etc.) at the project site. Because such equipment cannot be assumed to be needed for a particular land use project, a user must provide the data in order for CalEEMod to calculate the resulting emissions from off-road equipment operation. A dropdown list of off-road equipment is provided for the user to identify each piece of equipment. The model requires the following specific information per equipment type. The user would need to provide the number of pieces for each equipment type. The model assumes an operation activity of 8 hours per day and 260 days per year, as well as the horsepower and load factor of the equipment type, but the user has the ability to override the default assumptions with project specific information. Finally, the model assumes diesel fuel, but a dropdown menu is provided to allow the user to choose bio-diesel, compressed natural gas (CNG) or electrical if known, to power the equipment.

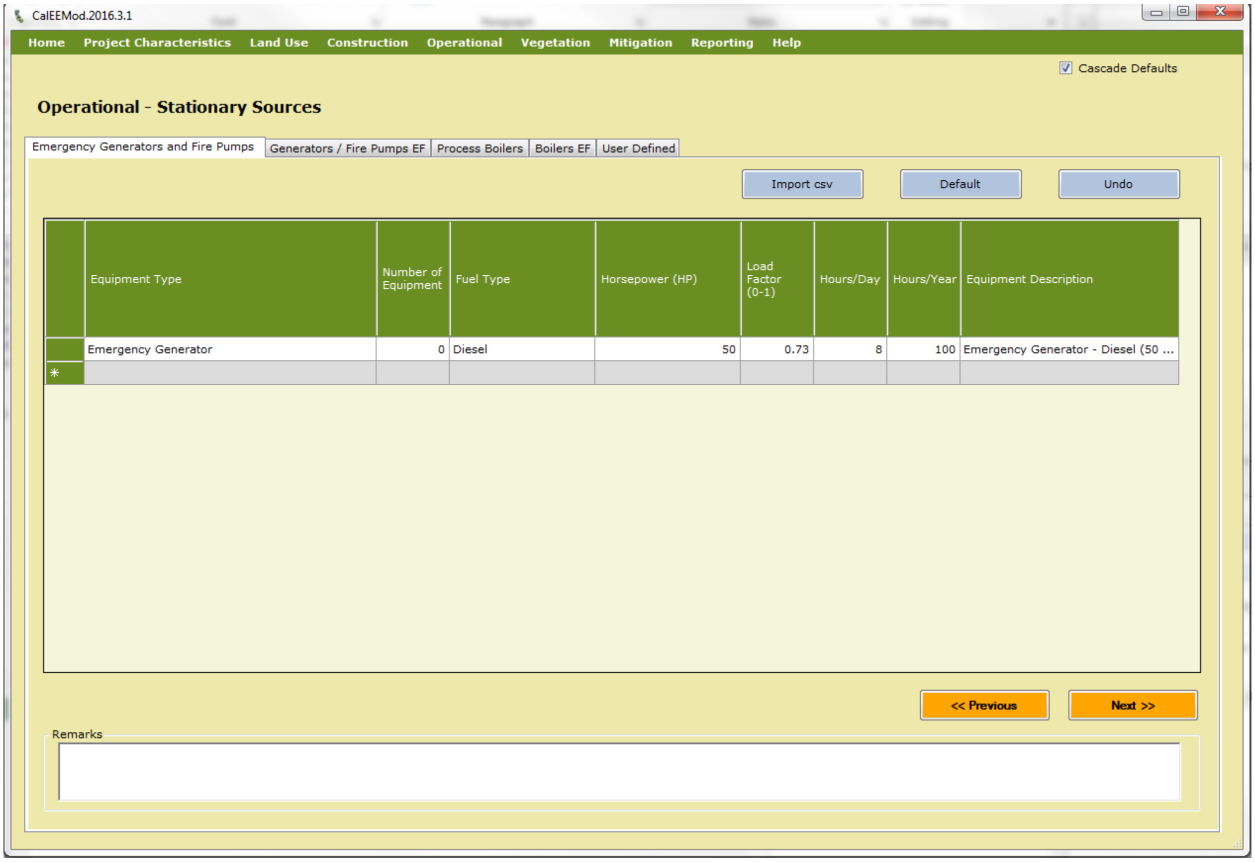


4.10 Stationary Sources

The Stationary Sources screen consists of five sub-screens: Emergency Generators and Fire Pumps and their default emission factors, Process Boilers and their default emission factors, and User Defined Sources. Consult with the local air district to determine if permitted stationary sources should be included in the project analysis using CalEEMod.

4.10.1 Emergency Generator and Fire Pumps and Default Emission Factors

Two sub-screens allow the user to enter emergency power generators and diesel fueled fire pumps and to estimate emissions. This type of equipment operates only for maintenance and testing, or during emergency situations, such as power failures. To calculate emissions, the user must enter the engine rating (in horsepower), the anticipated maximum daily usage, and the anticipated maximum annual usage into the Emergency Generators and Fire Pumps sub-screen. The user may change the default load factor. The default emission factors for the equipment are shown on the separate Generators/Fire Pumps EF (emission factor) sub-screen. The user can replace the default emission factors, but needs to provide custom emission factors in the predefined units. See Appendix A for the sources of default emission factors and emission calculation methodology.


CalEEMod.2016.3.1
Home
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Mitigation
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Help
Cascade Defaults
Operational - Stationary Sources
Emergency Generators and Fire Pumps
Generators / Fire Pumps EF
Process Boilers
Boilers EF
User Defined
Import csv
Default
Undo
Equipment Type
Number of Equipment
Fuel Type
Horsepower (HP)
Load Factor (0-1)
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Emergency Generator - Diesel (50 ...
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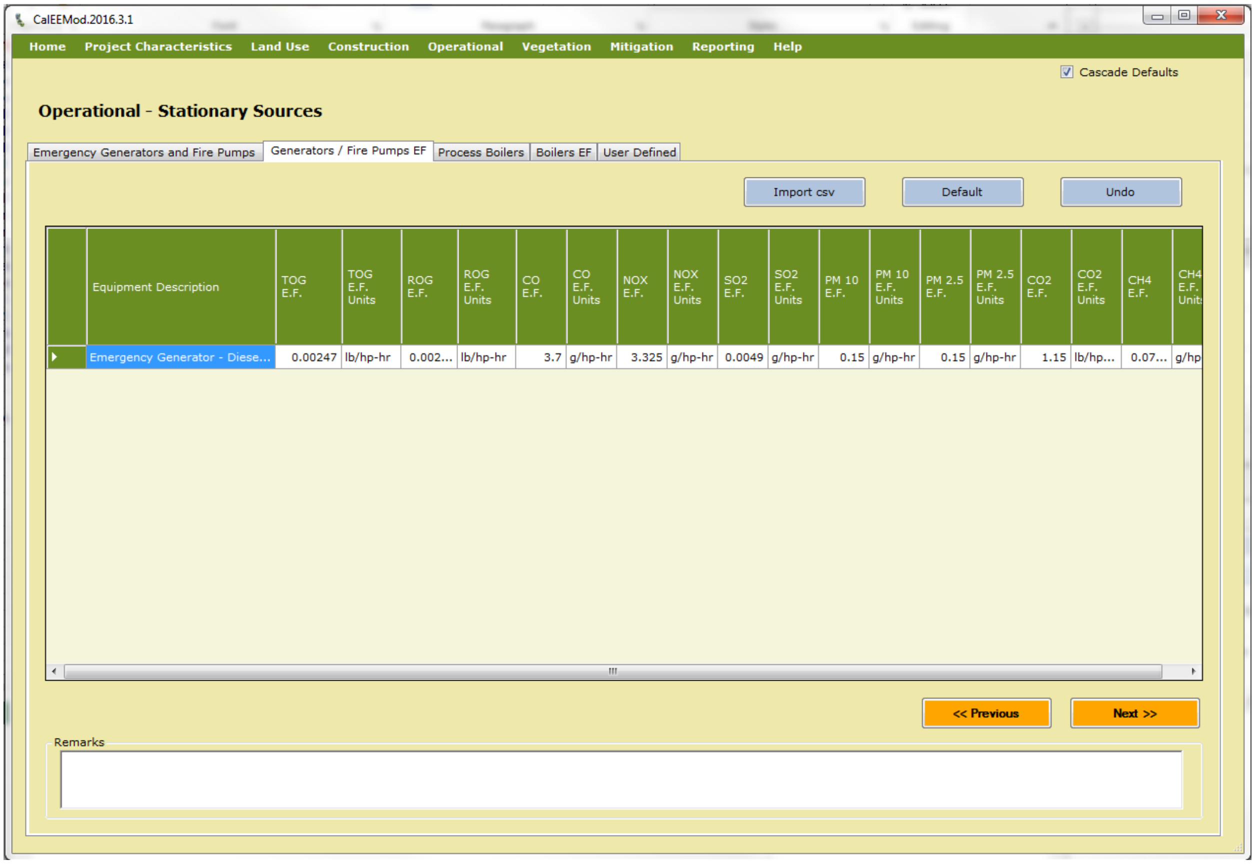
Remarks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Emergency Generators and Fire Pumps
Generators / Fire Pumps EF
Process Boilers
Boilers EF
User Defined
Import csv
Default
Undo
Equipment Description
TOG E.F.
TOG E.F. Units
ROG E.F.
ROG E.F. Units
CO E.F.
CO E.F. Units
NOX E.F.
NOX E.F. Units
SO2 E.F.
SO2 E.F. Units
PM 10 E.F.
PM 10 E.F. Units
PM 2.5 E.F.
PM 2.5 E.F. Units
CO2 E.F.
CO2 E.F. Units
CH4 E.F.
Emergency Generator - Diese...
0.00247
lb/hp-hr
0.002...
lb/hp-hr
3.7
g/hp-hr
3.325
g/hp-hr
0.0049
g/hp-hr
0.15
g/hp-hr
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g/hp-hr
1.15
lb/hp...
0.07...
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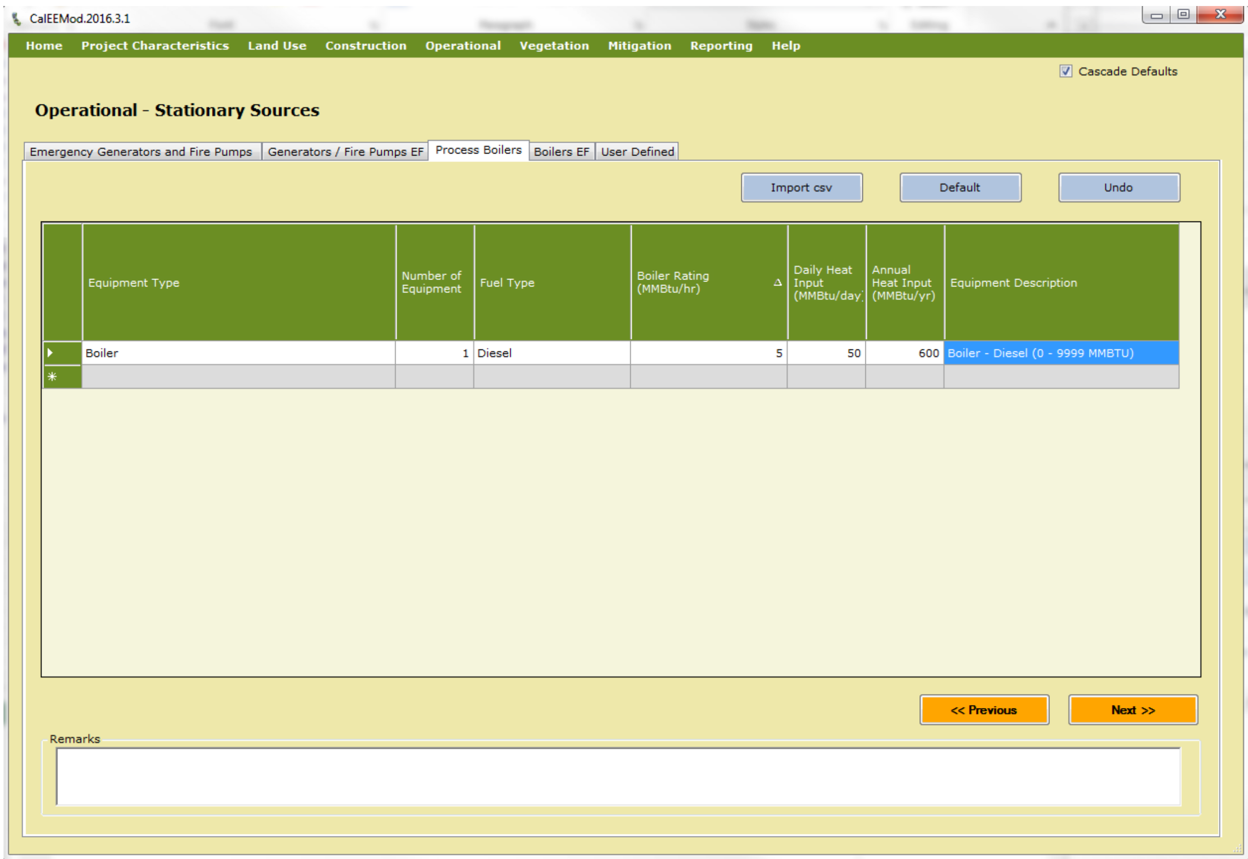
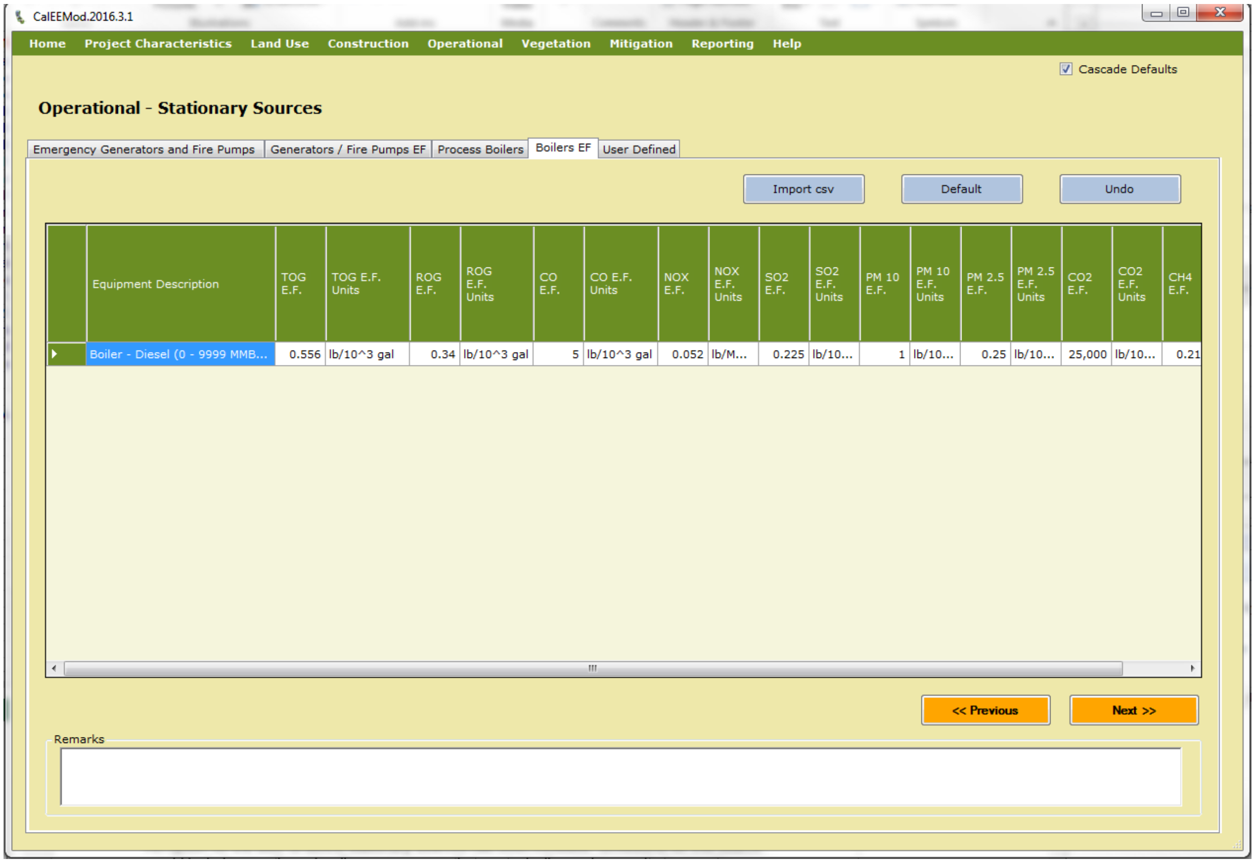
4.10.2 Process Boilers and Default Emission Factors

Two sub-screens allow the user to enter process boilers and to estimate emissions. Do not use this option for boilers providing space heating or building hot water, as these uses are included building energy use (See Subchapter 4.6). To calculate process boiler emissions, the user must enter the boiler rating (in million BTU/hr) and maximum anticipated daily and annual heat input in the Process Boilers sub-screen. The default emission factors for boilers are shown on the separate Boiler EF (emission factor) sub-screen. The user can replace the default emission factors, but needs to provide custom emission factors in the predefined units. See Appendix A for the sources of default emission factors and emission calculation methodology.

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Home
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Help
Cascade Defaults
Operational - Stationary Sources
Emergency Generators and Fire Pumps
Generators / Fire Pumps EF
Process Boilers
Boilers EF
User Defined
Import csv
Default
Undo
Equipment Description
TOG E.F.
TOG E.F. Units
ROG E.F.
ROG E.F. Units
CO E.F.
CO E.F. Units
NOX E.F.
NOX E.F. Units
SO2 E.F.
SO2 E.F. Units
PM 10 E.F.
PM 10 E.F. Units
PM 2.5 E.F.
PM 2.5 E.F. Units
CO2 E.F.
CO2 E.F. Units
CH4 E.F.
Boiler - Diesel (0 - 9999 MMB...
0.556
lb/10^3 gal
0.34
lb/10^3 gal
5
lb/10^3 gal
0.052
lb/M...
0.225
lb/10...
1
lb/10...
0.25
lb/10...
25,000
lb/10...
0.21
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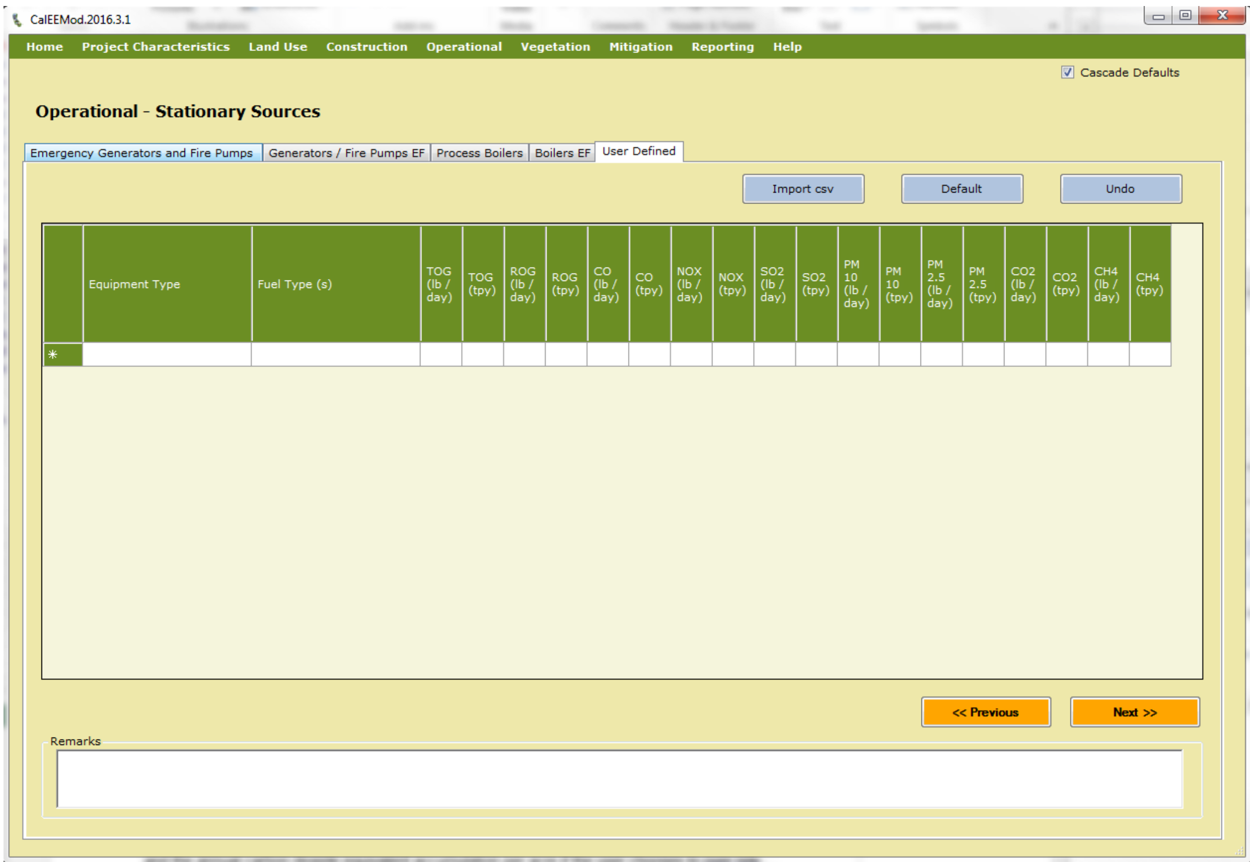
Remarks

4.10.3 User Defined

An option for the user to define stationary sources other than emergency generators, fire pumps and process boiler has been included in the User Defined sub-screen. Emissions for this source would include any other miscellaneous sources that typically require permits to operate issued by an air district. Emissions may be manually entered here, either by transferring values from the permits to operate, or by calculating emissions outside of CalEEMod. Any emissions entered here will be transferred to the appropriate reports.

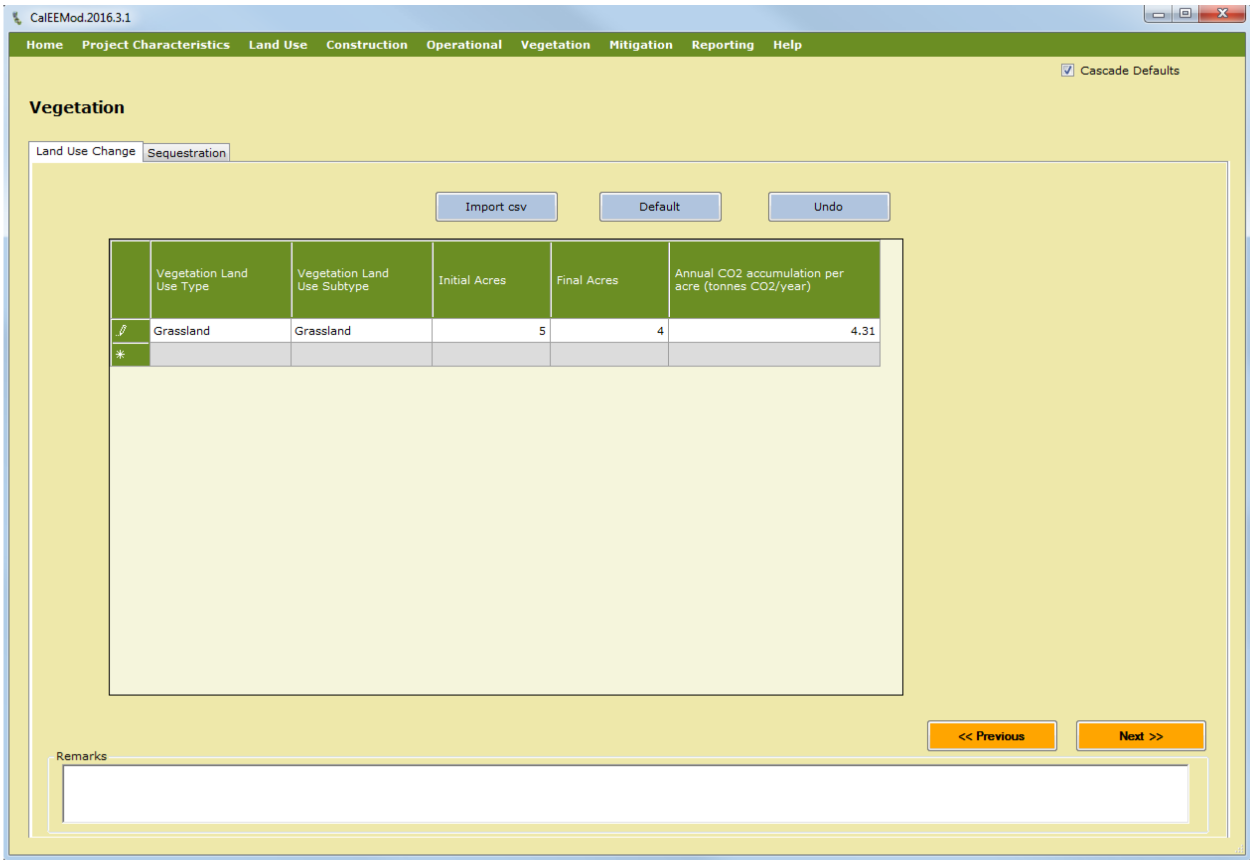


4.11 Vegetation

The vegetation screen is used to estimate the one-time change in carbon sequestration capacity due to a project. There are two sub-screens, Land Use Change and Sequestration. The methods used are based on IPCC[16].

4.11.1 Land Use Change

The Land Use Change sub-screen estimates GHG emissions due to a change in vegetation resulting from a change in land use type. The user enters the vegetation land use type, the initial and final acreage of the vegetation land use type, and the annual carbon dioxide equivalent accumulation per acre if the user chooses to override the default value. Settlement land use acreage is not considered since it is a net zero at steady state unless trees are added.



4.11.2 Sequestration

This sub-screen of Vegetation is used to estimate the GHG emissions associated with the sequestration of net new trees added to the project site. Consistent with IPCC recommendations a 20 year active growth period is assumed. The user enters the tree type or

16 IPCC. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 4. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

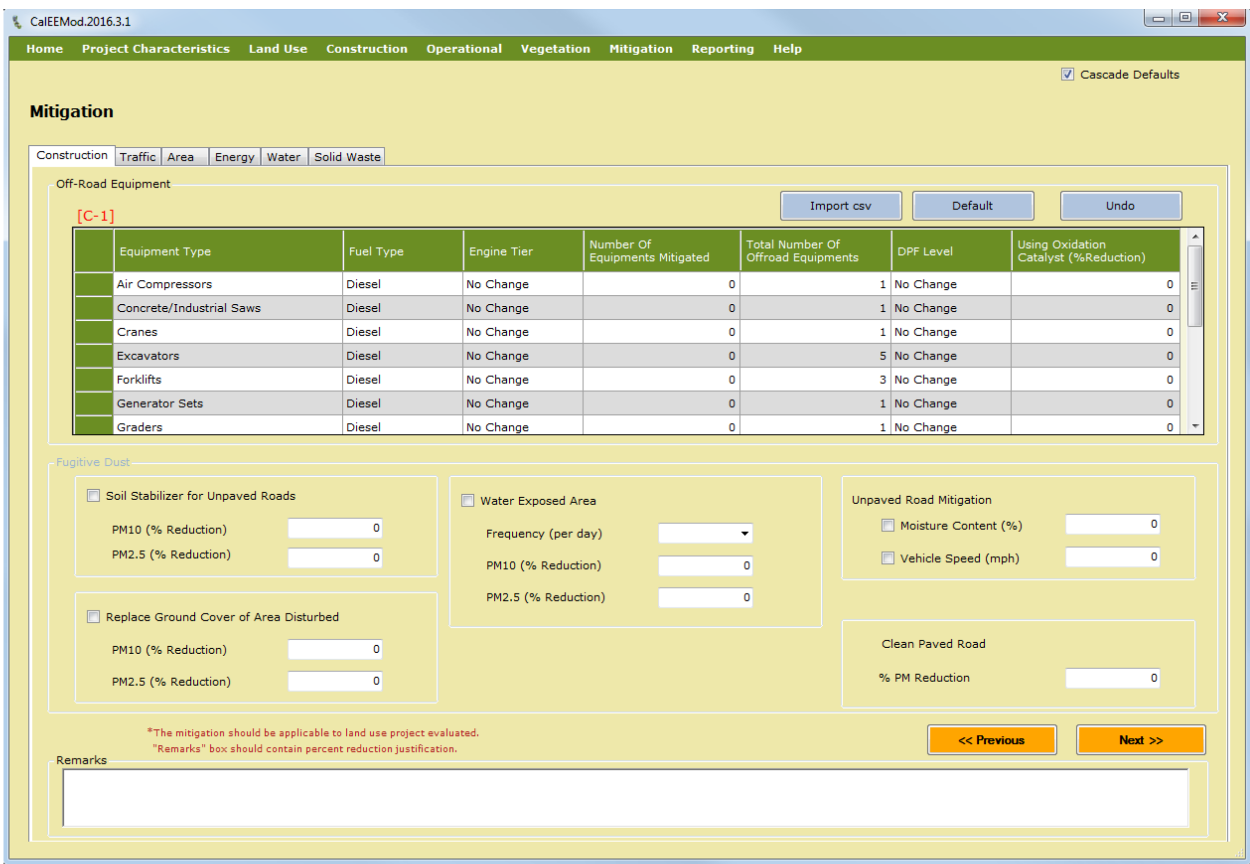
miscellaneous if it is not known, and the total number of trees. The user can override the default carbon sequestration rate.

4.12 Mitigation

The mitigation screen consists of six sub-screens that the user can indicate and supply the necessary information to estimate the emissions after mitigation measures have been implemented. The mitigation measures included in CalEEMod are largely based on the CAPCOA Quantifying Greenhouse Gas Mitigation Measures (http://www.capcoa.org/wp-content/uploads/downloads/2010/09/CAPCOA-Quantification-Report-9-14-Final.pdf) document. The CAPCOA measure numbers are provided next to the mitigation measures in CalEEMod to assist the user in understanding each measure by referencing back to the CAPCOA document.This User's Guide focuses on key aspects of the Mitigation sub-screens that users should pay particular attention.

4.12.1 Construction Mitigation

This sub-screen consists of a datagrid of off-road construction equipment to apply various mitigation measures and check boxes with supplemental information for fugitive dust emissions mitigation.



To apply mitigation to construction equipment, the user selects the equipment type, notes the number of equipment mitigated (of the total number of off-road equipment listed), and type of mitigation that applies. If substantial evidence supporting reductions was available at the time of development, options include fuel type (diesel, CNG, electric, hybrid, biodiesel), engine tier (typically select Tier 4), diesel particulate filter tiers (Tier 3 being the most effective), and use of oxidative catalysts. The program estimates how much if any increase or decrease in emissions to apply for each pollutant. Some mitigation measures have trade-offs in pollutant reductions and therefore may result in increases of some pollutants. The mitigation option to use alternative fuel for construction equipment is consistent with mitigation measure C-1 in the CAPCOA Quantifying GHG Mitigation document.

To apply mitigation to construction fugitive dust, the user selects the check box in front of the mitigation measure name, and enters in the appropriate information in the drop down or text boxes. Some fugitive dust mitigation required by some air districts do not appear here since the fugitive dust source they mitigate is not quantified by CalEEMod, in particular this includes fugitive dust generated by wind over land and storage piles. Since the fugitive dust source is not quantified it is not appropriate to apply the reduction.

For Unpaved Road Mitigation for construction fugitive dust, the maximum vehicle speed and the minimum moisture content for unpaved roads are entered. Defaults for these values are those entered on the On-Road Fugitive Dust screen. Mitigated emissions are calculated using the VMT from on-road vehicles traveling along unpaved roads, previously calculated from the percentages entered on the On-road Fugitive Dust Screen (e.g., % Pave Worker, % Pave Vendor or % Pave Hauling).

Users may check the boxes and provide a lower vehicle speed and a higher moisture content to conduct the mitigation calculation. If during a particular construction phase the user defined mitigated vehicle speed is higher than the unmitigated vehicle speed and/or the user defined mitigated moisture content is lower than the unmitigated moisture content, a warming message will be displayed. In this case, the unmitigated values will be used, resulting in no mitigation being calculated.

4.12.2 Traffic Mitigation

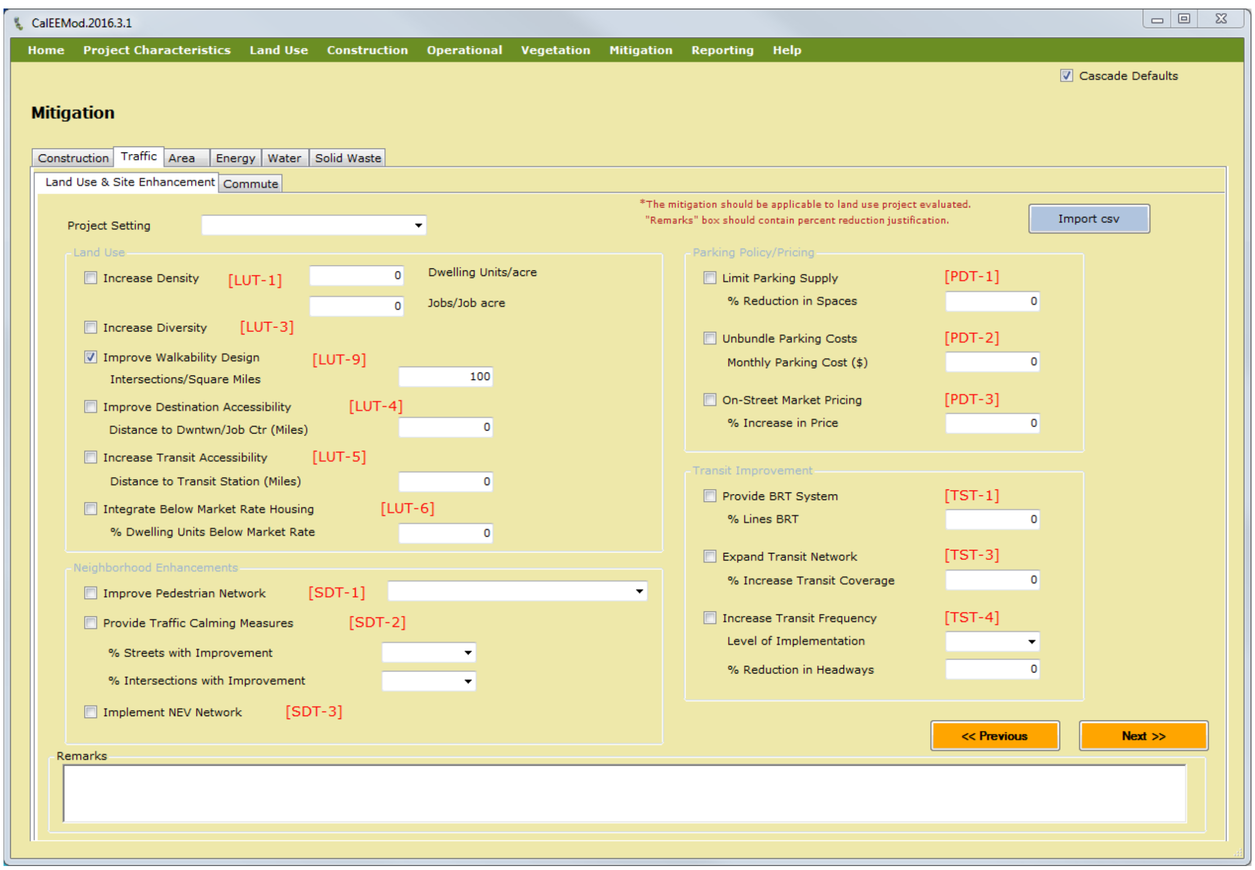
There are two traffic mitigation sub-screens that the user can select from, Land Use & Site Enhancement and Commute. First, the user must select the Project Setting as defined in the CAPCOA document (pp. 59-60).

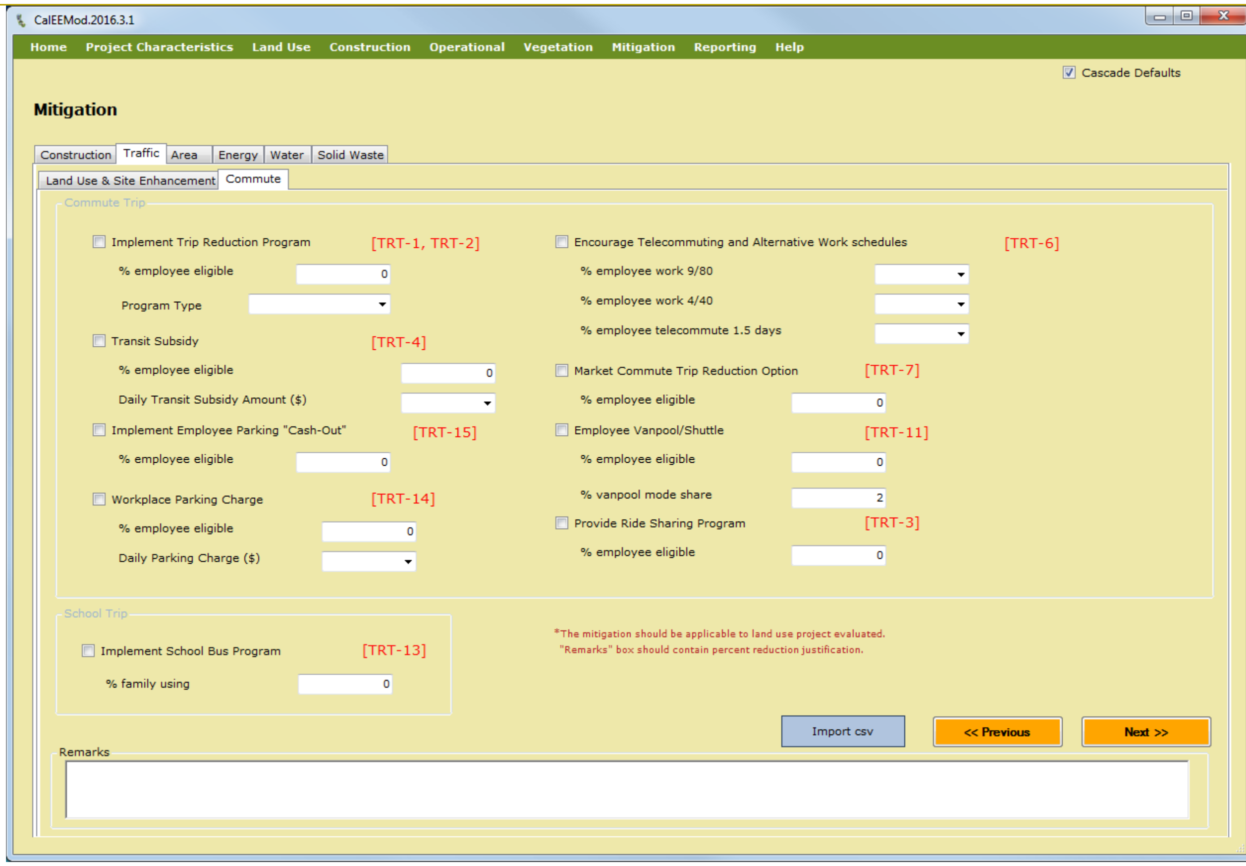
- Low Density Suburban: An area characterized by dispersed, low-density, single-use, automobile dependent land use patterns, usually outside of the central city (a suburb).
- Suburban Center: An area that serves the population of the suburb with office, retail and housing which is denser than the surrounding suburb.

- Urban: An area which is located within the central city with higher density of land uses than you would find in the suburbs. It may be characterized by multi-family housing and located near office and retail.
- Urban Center *(referred to as Compact Infill in the CAPCOA document)*: An area which is located within or contiguous with the central city. Examples may include redevelopment areas, abandoned sites, or underutilized older buildings/sites.

If the CAPCOA measure did not distinguish between Suburban Center and Low Density Suburban, values for Low Density Suburban were used. Similarly, if Urban Center and Urban values were not distinguished, Urban values were used.

The user checks the box next to each mitigation measure and fills in the appropriate information as required. The maximum reduction caps defined in the CAPCOA Quantifying GHG Mitigation document are integrated into these calculations. The CAPCOA traffic mitigation measure numbers included in CalEEMod are the following: LUT-1, LUT-3, LUT-9, LUT-4, LUT-5, LUT-6, SDT-1, SDT-2, SDT-3, PDT-1, PDT-2, PDT-3, TST-1, TST-3, TST-4, TRT-1, TRT-2, TRT-4, TRT-15, TRT-14, TRT-6, TRT-7, TRT-11,TRT-3, and TRT-13. The NEV network mitigation measure (SDT-3) assumes the low end of the CAPCOA recommendations.

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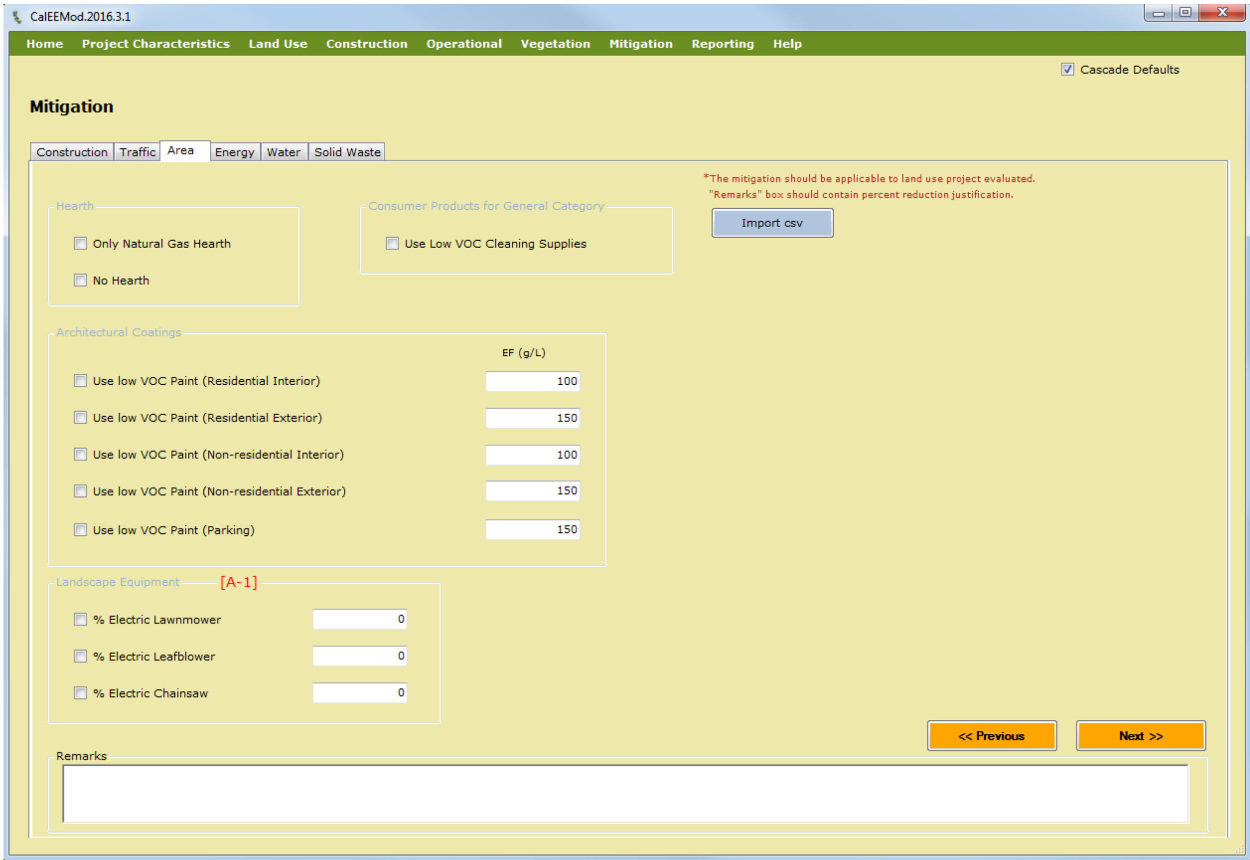
Commute
Commute Trip
Implement Trip Reduction Program
[TRT-1, TRT-2]
% employee eligible
0
Program Type
Transit Subsidy
[TRT-4]
% employee eligible
0
Daily Transit Subsidy Amount ($)
Implement Employee Parking "Cash-Out"
[TRT-15]
% employee eligible
0
Workplace Parking Charge
[TRT-14]
% employee eligible
0
Daily Parking Charge ($)
Encourage Telecommuting and Alternative Work schedules
[TRT-6]
% employee work 9/80
% employee work 4/40
% employee telecommute 1.5 days
Market Commute Trip Reduction Option
[TRT-7]
% employee eligible
0
Employee Vanpool/Shuttle
[TRT-11]
% employee eligible
0
% vanpool mode share
2
Provide Ride Sharing Program
[TRT-3]
% employee eligible
0
School Trip
Implement School Bus Program
[TRT-13]
% family using
0
*The mitigation should be applicable to land use project evaluated.
"Remarks" box should contain percent reduction justification.
Import csv
<< Previous
Next >>
Remarks

4.12.3 Area Mitigation

The user can select from a few area source mitigation measures on the Area sub-screen by checking the appropriate box and supplying any additional information in the text boxes. These measures include all natural gas hearths, no hearths, electric landscaping equipment use, reduced ROG coatings, and reduced general category consumer product ROG content. The area landscaping mitigation to prohibit gas powered landscape equipment is consistent with mitigation A-1 in the CAPCOA Quantifying GHG Mitigation document.

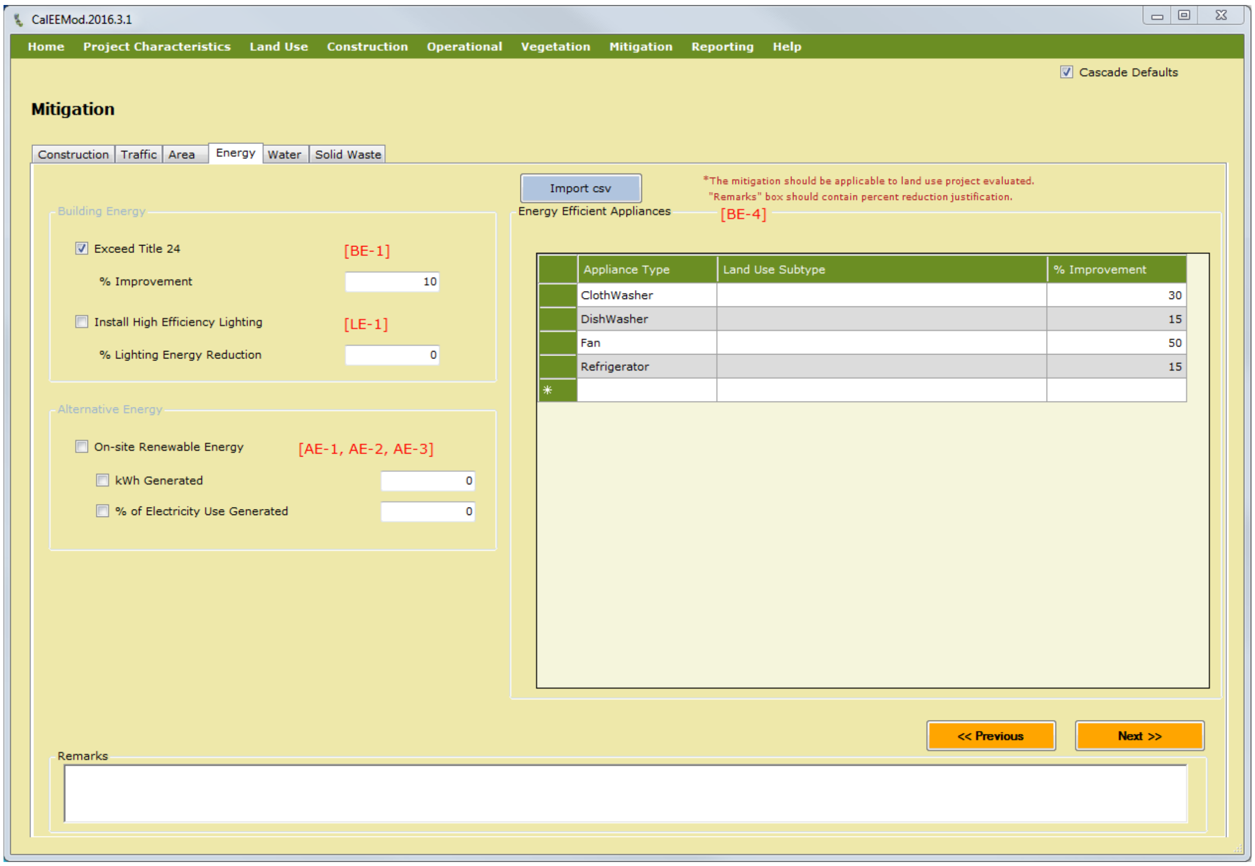


4.12.4 Energy Mitigation

The user selects energy mitigation measures on the Energy sub-screen by using the check boxes or the datagrid. These correspond to CAPCOA Mitigation Measures LE-1, BE-1, AE-1, AE-2, AE-3 and BE-4 as listed in the CAPCOA Quantifying GHG Mitigation document. The lighting is a percentage reduction in lighting as supplied by the user. The datagrid is used to enter the land use subtypes that will use energy efficient appliances. The percent improvement is the typical percent improvement above standard appliances according to the 2008 Energy Star Annual Report[17]. Alternative Energy has two methods to enter the amount of alternative energy. The first is the amount of kW-hr generated. The second is the percentage of the total

17 Available at: https://www.energystar.gov/ia/partners/annualreports/annual_report_2008.pdf

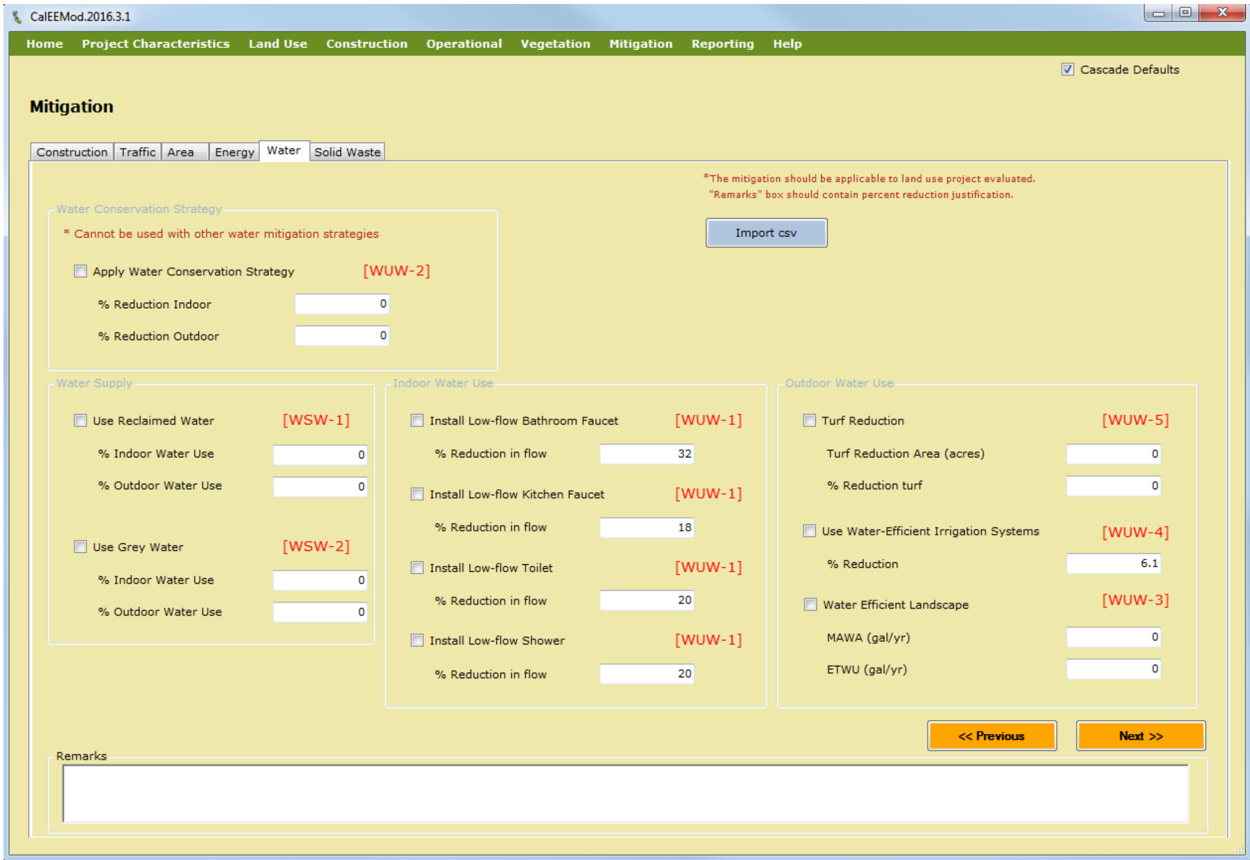
electricity use by buildings that is generated. At this time alternative energy methods that are not carbon neutral are not quantified. To apply the amount of alternative energy only one of the two methods (kW-hr or percentage) needs to be entered for CalEEMod to calculate emission reductions.



4.12.5 Water Mitigation

On the Water sub-screen, water mitigation can either be estimated as the percent reduction based on a water conservation strategy or the other individual mitigation measures. The CAPCOA Quantifying GHG Mitigation document includes water supply and use measures WSW-1 & 2, and WUW-1 through 5.

For CAPCOA Mitigation Measure WSW- 3 (Use Locally Sourced Water Supply), using locally-sourced water or water from less energy-intensive sources reduces the electricity and indirect CO_2 emissions associated with water supply and transport because water from local or nearby groundwater basins, nearby surface water and gravity-dominated systems have smaller energy-intensity factors. This mitigation measure is not included in the Water mitigation sub-screen, therefore, to implement WSW-3, the user should alter the energy intensity values in water and run a separate CalEEMod run to accommodate these values.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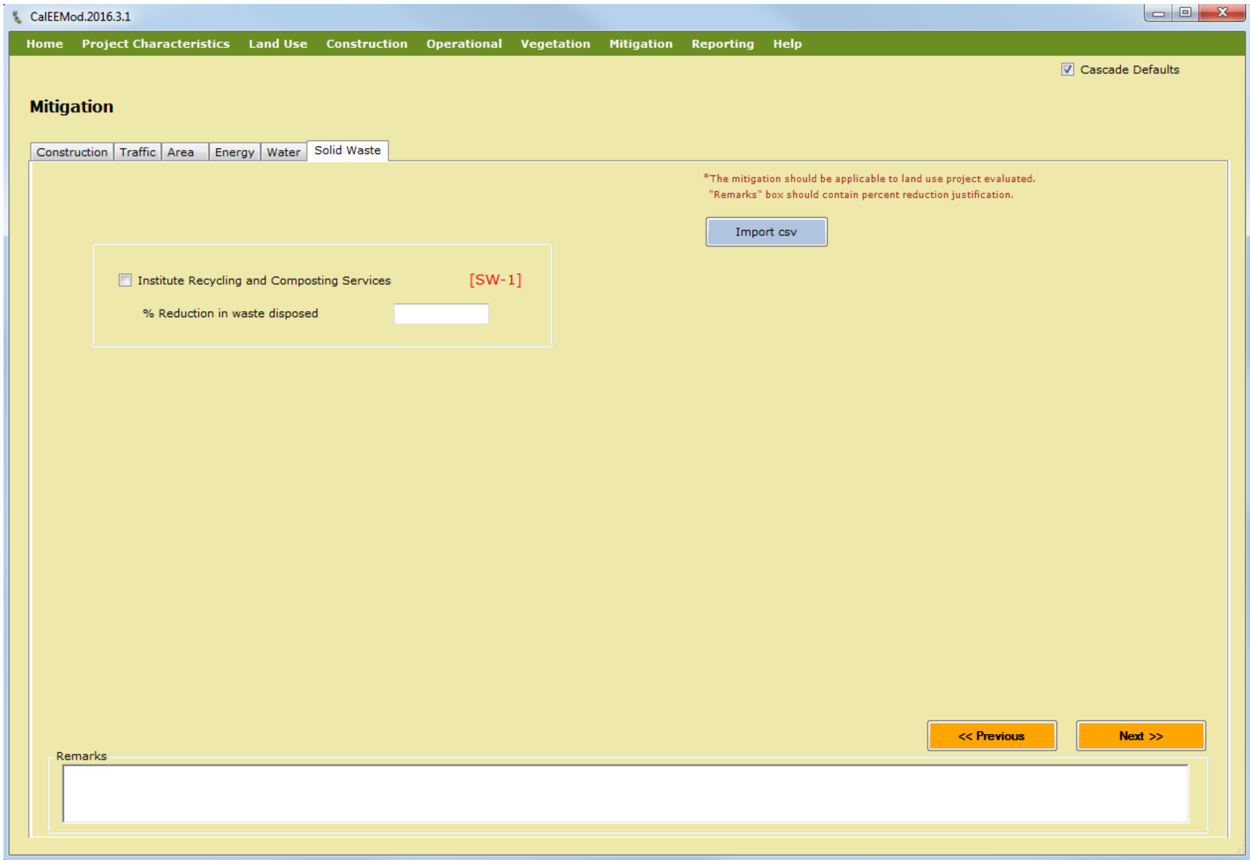
*The mitigation should be applicable to land use project evaluated.
"Remarks" box should contain percent reduction justification.
Import csv
Water Conservation Strategy
* Cannot be used with other water mitigation strategies
Apply Water Conservation Strategy [WUW-2]
% Reduction Indoor 0
% Reduction Outdoor 0
Water Supply
Use Reclaimed Water [WSW-1]
% Indoor Water Use 0
% Outdoor Water Use 0
Use Grey Water [WSW-2]
% Indoor Water Use 0
% Outdoor Water Use 0
Indoor Water Use
Install Low-flow Bathroom Faucet [WUW-1]
% Reduction in flow 32
Install Low-flow Kitchen Faucet [WUW-1]
% Reduction in flow 18
Install Low-flow Toilet [WUW-1]
% Reduction in flow 20
Install Low-flow Shower [WUW-1]
% Reduction in flow 20
Outdoor Water Use
Turf Reduction [WUW-5]
Turf Reduction Area (acres) 0
% Reduction turf 0
Use Water-Efficient Irrigation Systems [WUW-4]
% Reduction 6.1
Water Efficient Landscape [WUW-3]
MAWA (gal/yr) 0
ETWU (gal/yr) 0
<< Previous
Next >>
Remarks

4.12.6 Solid Waste Mitigation

The user can get calculate an emissions reduction for recycling waste. This mitigation measure corresponds to CAPCOA Mitigation Measure: SW-1.



4.13 Reporting

The user initiates final emission calculations by selecting the report and clicking on the Recalculate All Emissions and Run Report button. The available reports include: Annual, Summer (peak) Daily, Winter (peak) Daily, Mitigation and Summary of peak daily emissions and annual GHG emissions. A separate report viewer will come up. From this report viewer, the user can view their report on-screen, print reports, save as Microsoft Excel xls file or save as an Adobe Acrobat pdf file, or in the case of the Mitigation report, a Microsoft Word doc file. The data in the Excel file has already been calculated and placed in the grids as text, thus, for example, the user cannot change an emission value and expect the report to change the summed total value. These values, however, can be copied to new Excel spreadsheet for any further desired calculation with the data.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CalEEMod®

California Emissions Estimator Model®

User's Guide

Version 2016.3.2

Prepared for:
California Air Pollution Control Officers Association (CAPCOA)

Prepared by:
BREEZE Software, A Division of Trinity Consultants
in collaboration with South Coast Air Quality Management District and the California Air Districts

Date:
November 2017

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1 Introduction

This User's Guide (Guide) to the California Emission Estimator Model (CalEEMod)® is meant to give the user an introduction on how to use the program as well as to document the detailed calculations and default assumptions made in associated appendices. The purpose of CalEEMod is to provide a uniform platform for government agencies, land use planners, and environmental professionals to estimate potential emissions associated with both construction and operational use of land use projects. It is intended that these emission estimates are suitable for quantifying air quality and climate change impacts as part of the preparation of California Environmental Quality Act (CEQA) documents. In addition, individual districts may rely on the model's emission estimates to show compliance with local agency rules.

CalEEMod utilizes widely accepted methodologies for estimating emissions combined with default data that can be used when site-specific information is not available. Sources of these methodologies and default data include but are not limited to the United States Environmental Protection Agency (USEPA) AP-42 emission factors, California Air Resources Board (CARB) vehicle emission models, studies commissioned by California agencies such as the California Energy Commission (CEC) and CalRecycle. In addition, some local air districts provided customized values for their default data and existing regulation methodologies for use for projects located in their jurisdictions. When no customized information was provided and no regional differences were defined for local air districts, then state-wide default values were utilized. Since resource data and regulations are constantly changing, local agencies should be consulted to determine whether there are any circumstances when updated values should be used in place of the defaults currently incorporated into CalEEMod. A majority of CalEEMod's default data associated with locations and land use is derived from surveys of existing land uses. For any project that substantially deviates from the types and features included in the surveys, site-specific data that are supported by substantial evidence should be used, if available.

The model provides a number of opportunities for the user to change the defaults in the model; however, users are required to provide justification for all changes made to the default settings (e.g., reference more appropriate data sources) in the Remarks box provided at the bottom of the screen before the user will be able to proceed to the next screen. Further, the user should make every effort to ensure that correct data is entered, including the choice and percent reduction of mitigation most applicable to the land use project being evaluated.

1.1 Purpose of Model

CalEEMod provides a simple platform to calculate both construction emissions and operational emissions from a land use project. It can calculate both the daily maximum and annual average for criteria pollutants as well as annual greenhouse gas (GHG) emissions. The output from these calculations can be used in the preparation of quality and GHG analyses in CEQA documents such as Environmental Impact Reports (EIRs) and Negative Declarations. For projects located in the jurisdiction of San Luis Obispo APCD, the model can also calculate the sum of reactive organic gas (ROG) and nitrogen oxide (NO_X) emissions on a rolling quarterly basis. In addition, CalEEMod contains default values for estimating water and energy use which may be useful for preparing hydrology and energy analyses in other sections of a CEQA document. Specifically, the model can aid the user by conducting the following calculations:

- Short-term construction emissions associated with the demolition, site preparation, grading, building, coating, and paving from the following sources:
  - Off-road construction equipment;
  - On-road mobile equipment associated with workers, vendors, and hauling;
  - Fugitive dust associated with grading, demolition, truck loading, and on-road vehicles traveling along paved and unpaved roads. (Fugitive dust from windblown sources such as storage piles and inactive disturbed areas, as well as fugitive dust from off-road vehicle travel, are not quantified in CalEEMod, which is consistent with approaches taken in other comprehensive models.)
  - Architectural coating activities *(including the painting/striping of parking lots)* and paving (ROG).
- Operational emissions for fully built-out land use development from the following sources:
  - On-road mobile vehicle traffic generated by the land uses;
  - Fugitive dust associated with roads;
  - Architectural coating activities (ROG);
  - Off-road equipment (e.g., forklifts, cranes) used during operation;
  - Landscaping equipment;
  - Emergency generators, fire pumps, and process boilers;
  - Use of consumer products, parking lot degreasers, fertilizers/pesticides, and cleaning supplies (ROG);
  - Wood stoves and hearth usage;
  - Natural gas usage in the buildings;
  - Electricity usage in the buildings (GHG only);
  - Electricity usage from lighting in parking lots and lighting, ventilation and elevators in parking structures;
  - Water usage per land use (GHG only); and,
  - Solid waste disposal per land use (GHG only).
- One-time vegetation sequestration changes
  - Permanent vegetation land use changes
  - New tree plantings

- Mitigation adjustments to both short-term construction and operational emissions. Several of the mitigation measures described in CAPCOA's Quantifying Greenhouse Gas Mitigation Measures[1] have been incorporated into CalEEMod.

[1] Available at: http://www.capcoa.org/wp-content/uploads/2010/11/CAPCOA-Quantification-Report-9-14-Final.pdf

2 Program Installation

The program is distributed and maintained by the California Air Pollution Control Officers Association[2]. The most recent version can be downloaded from www.caleemod.com.

2.1 Operating System Requirements

CalEEMod was programmed by Trinity using Microsoft SQL Compact Edition in conjunction with a Visual Basic Graphical User Interface (GUI). CalEEMod requires the following system requirements:

- Microsoft Windows 8 or 10 Operating System with Microsoft .NET Framework 3.5 (includes .NET 2.0 and 3.0)
- Microsoft Windows XP, Vista, or 7 Operating System with Microsoft .Net Framework 4 or higher
- Microsoft SQL Server Compact 3.5 SP2
- Microsoft Access Database Engine 2010 Redistributable, 32-bit
- 300 Mb hard drive space available

2.2 Installation Procedures

To install:

1. Ensure you have the required Microsoft .Net framework installed on your machine. Microsoft .NET Framework 3.5 is available for free from Microsoft at: https://www.microsoft.com/en-us/download/details.aspx?id=21. Microsoft .NET Framework 4.0 or higher is available free from Microsoft at: https://www.microsoft.com/en-us/download/details.aspx?id=17851. Once the file is downloaded, unzip the file anywhere on your computer and run the installation file (setup.exe) and follow the instructions on Microsoft's website to locate the appropriate .msi file.

2. To install Microsoft SQL Server Compact 3.5 SP2, go to https://www.microsoft.com/en-us/download/details.aspx?id=5783. For 32-bit computers, you will need to install SSCERuntime_x86-ENU.msi. For a 64-bit computer, you will need to install both the 32-bit and the 64-bit version of the SQL Server Compact 3.5 SP2 MSI files because the existing SQL Server Compact 3.5 applications may fail if only the 32-bit version of the .msi file is installed on the 64-bit computer.

3. To install 32-bit Microsoft Access Database Engine 2010 Redistributable, go to https://www.microsoft.com/en-us/download/details.aspx?id=13255&751be11f-ede8-5a0c-058c-2ee190a24fa6=True, click on Download, select "AccessDatabaseEngine.exe" (25.3 MB), and click on Next. Once this file is

downloaded, double click on "AccessDatabaseEngine.exe" file and follow the on-screen instructions to finish the installation.

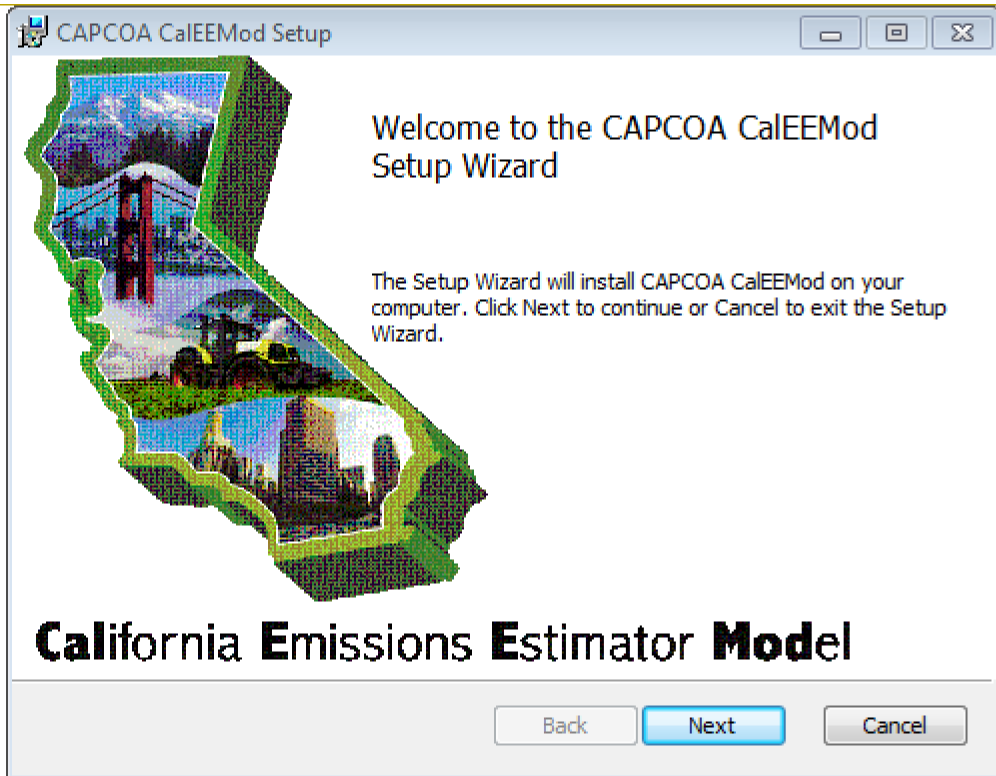
4. From www.CalEEMod.com, download the installation file (CalEEMod.WixSetup 2016.3.2.25.msi), click on the file and follow the instructions. Pages 6 through 8 show screen shots of the CalEEMod Windows Installer XML (WiX) Setup Wizard.

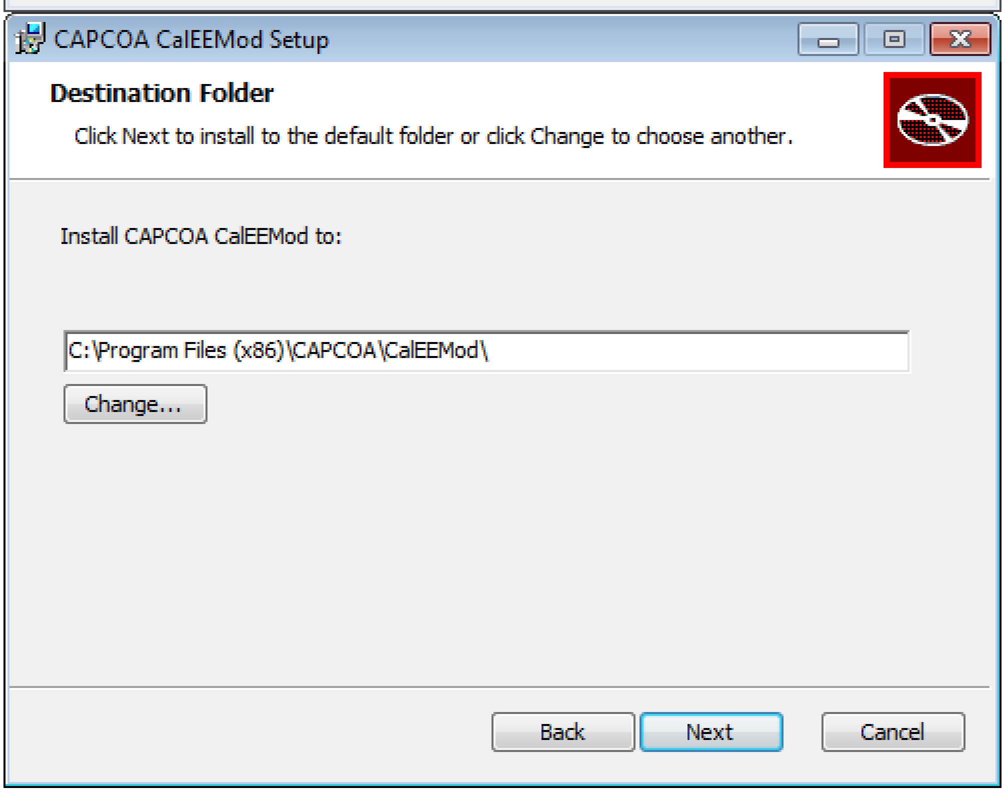
5. CalEEMod version 2016.3.2 can be installed side by side with version 2016.3.1 provided that each version is installed in different folders. For 32-bit computers, the default directory for CalEEMod version 2016.3.2 is C:\Program Files\CAPCOA\CalEEMod; for 64-bit computers, the default directory for CalEEMod version 2016.3.2 is C:\Program Files (x86)\CAPCOA\CalEEMod. If you want to run CalEEMod version 2016.3.2 side by side with CalEEMod version 2016.3.1 but CalEEMod version 2016.3.1 is already installed in C:\Program Files\CAPCOA\CalEEMod on a 32-bit computer or C:\Program Files (x86)\CAPCOA\CalEEMod on a 64-bit computer, click on Change to change the destination folder[3].

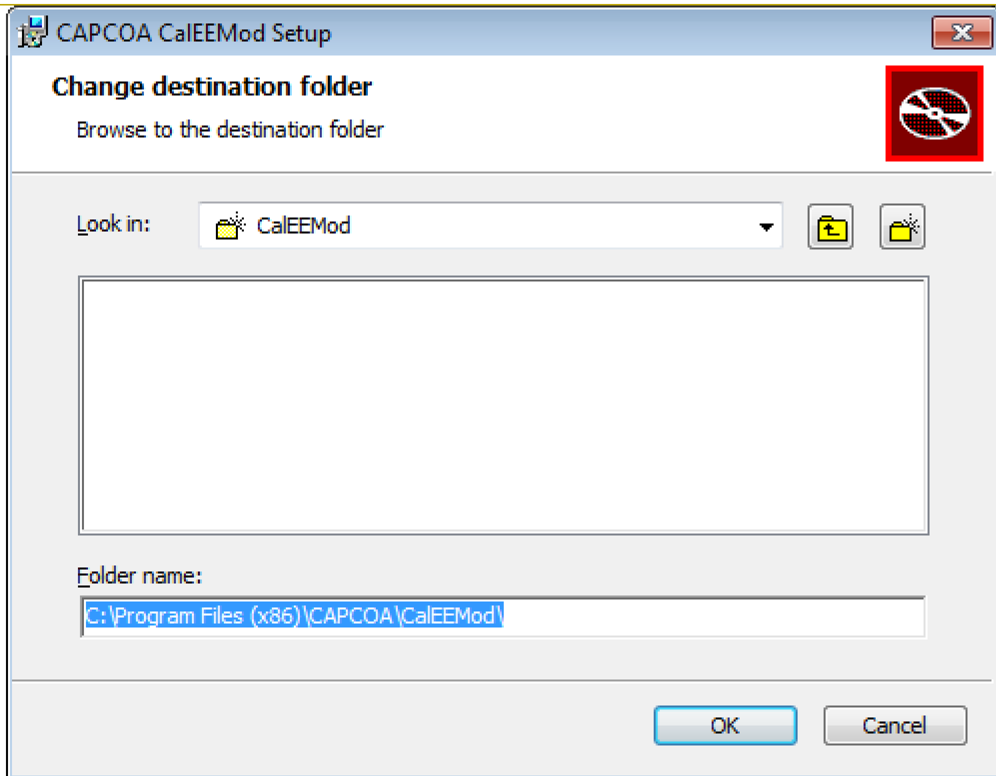
6. Click Next until the installation has completed, then click Finish to exit the installer.

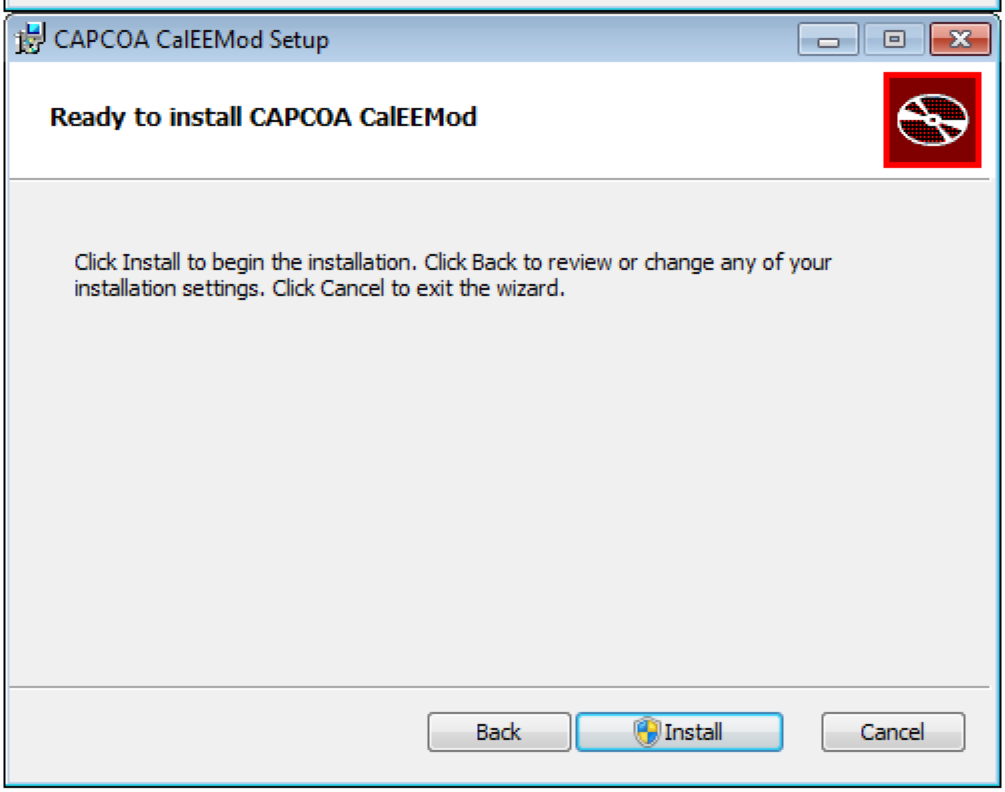
7. If you have any further trouble installing CalEEMod, verify that you have appropriate user privileges and that your computer meets the operating system requirements.

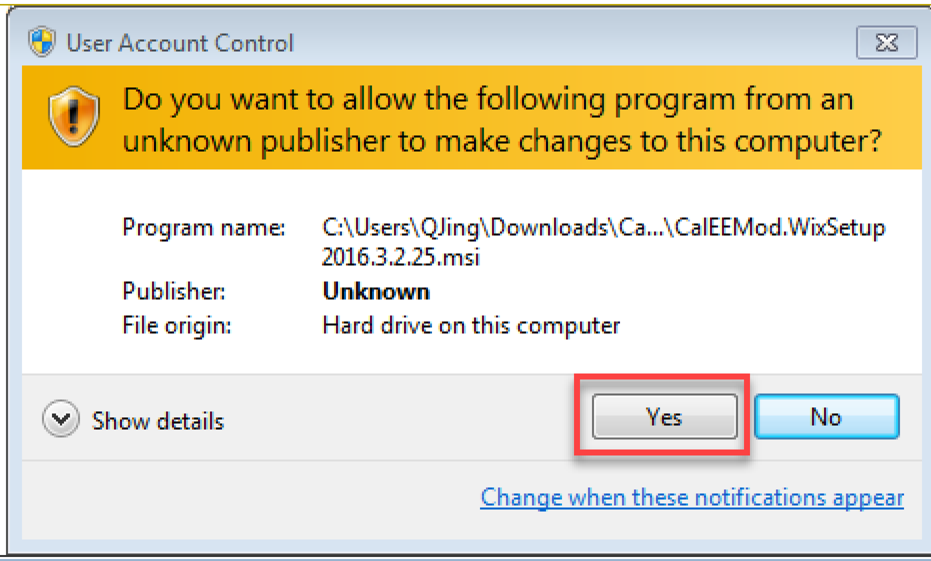
[3] If you use Windows Vista, 7, 8 or 10, file privileges may not allow access rights to some folders during program operations such as C:\Program Files\.

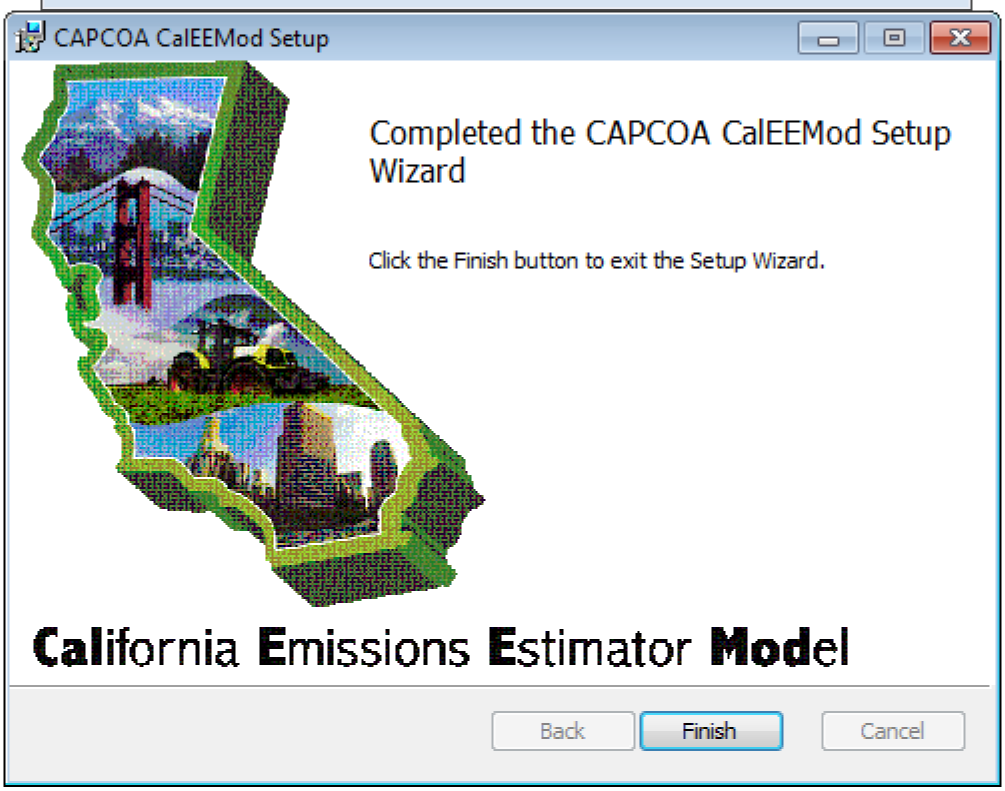

CAPCOA CalEEMod Setup
Welcome to the CAPCOA CalEEMod Setup Wizard
The Setup Wizard will install CAPCOA CalEEMod on your computer. Click Next to continue or Cancel to exit the Setup Wizard.
California Emissions Estimator Model
Back
Next
Cancel


CAPCOA CalEEMod Setup
Destination Folder
Click Next to install to the default folder or click Change to choose another.
Install CAPCOA CalEEMod to:
C:\Program Files (x86)\CAPCOA\CalEEMod\
Change...
Back
Next
Cancel


CAPCOA CalEEMod Setup
Change destination folder
Browse to the destination folder
Look in:
CalEEMod
Folder name:
C:\Program Files (x86)\CAPCOA\CalEEMod\
OK
Cancel

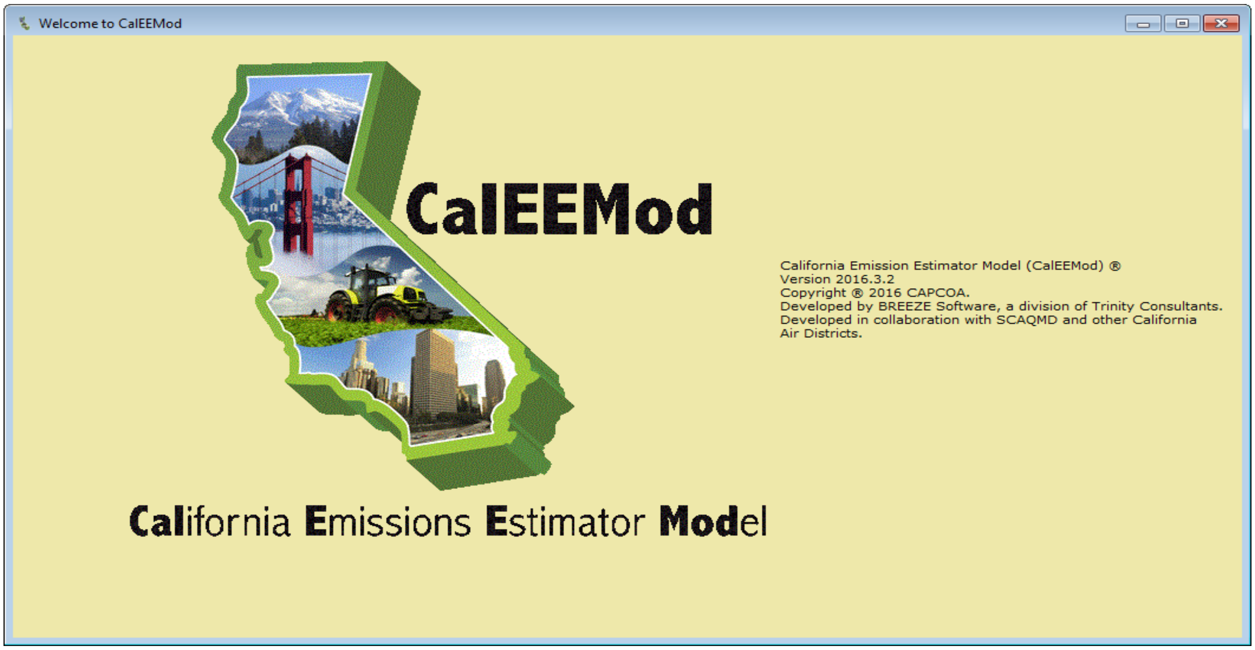

CAPCOA CalEEMod Setup
Ready to install CAPCOA CalEEMod
Click Install to begin the installation. Click Back to review or change any of your installation settings. Click Cancel to exit the wizard.
Back
Install
Cancel


User Account Control
Do you want to allow the following program from an unknown publisher to make changes to this computer?
Program name: C:\Users\QJing\Downloads\Ca...\CalEEMod.WixSetup 2016.3.2.25.msi
Publisher: Unknown
File origin: Hard drive on this computer
Show details
Yes
No
Change when these notifications appear


CAPCOA CalEEMod Setup
Completed the CAPCOA CalEEMod Setup Wizard
Click the Finish button to exit the Setup Wizard.
California Emissions Estimator Model
Back
Finish
Cancel

2.3 Starting CalEEMod

After the installation is complete, a CalEEMod short cut icon will be appear on the desktop and CalEEMod will appear in the list of Programs available from the Start Button. To start the model, select CalEEMod from the program files or double click on the CalEEMod short cut icon.



3 Using CalEEMod

3.1 Key Features

CalEEMod is comprised of a linear series of screens with each screen designed with an individual purpose to define features of the project such as project characteristics, construction schedule and equipment, operational activity, mitigation measures, etc. The user will need to input basic information about the project such as location, land use type (e.g., residential, commercial, retail, etc.) and project size and the model will populate later screens with pre-determined defaults. The user may override the defaults to input more accurate, project-specific information as appropriate.

The figure on page 11 identifies some key features of CalEEMod which are described below.

1. Menu Bar: A drop down menu bar is found on all screens. For example, the Home menu controls file features such as New Project, Open Project, Save Project, and Save As Project. The Help menu will link to appropriate information for the relevant screen from this User's Guide. All of the other menus will allow navigation between the screens in any order.

2. Screen Name: Identifies the name of the current screen.

3. Default Button: This button allows the user to restore the program defaults after the user has changed any default values on the screen. User-entered values will be highlighted in yellow to clearly indicate the defaults that have been changed. The user will be prompted to specify whether the default should be restored for the current or last cell on the screen or for the entire screen. The Import csv option will allow the user to load in a .csv file for a specific data grid. Clicking on the Undo button will allow the user to cancel or undo the previous action.

4. Remarks: This section is located at the bottom of each screen and it requires the user to enter comments regarding any defaults that have been replaced with user-defined values. The Remarks section is meant to assist project reviewers to determine or assess the justification for user-defined values entered.

5. Next Button: When the user clicks on this button, the next sequential screen will appear. As the user progresses through the model, later screens will also show a Previous button that will take the user to the previous screen.

6. Data Grid: This is a common box where values for the variables defined across the top are to be filled in with data. The number of rows will automatically be adjusted based on the number of rows of information required to define the information. On some data grids, the last row may have an asterisk (*) and once the user begins adding information to this row, a new row will be added at the end. To delete a row, select the desired row to delete, and hit the delete button on your keyboard. (Deleting information is generally allowed unless the data grid contains a fixed list such as the Pollutant selection list.) Scroll bars (both horizontal and vertical) may also occur on some data grids, as appropriate.

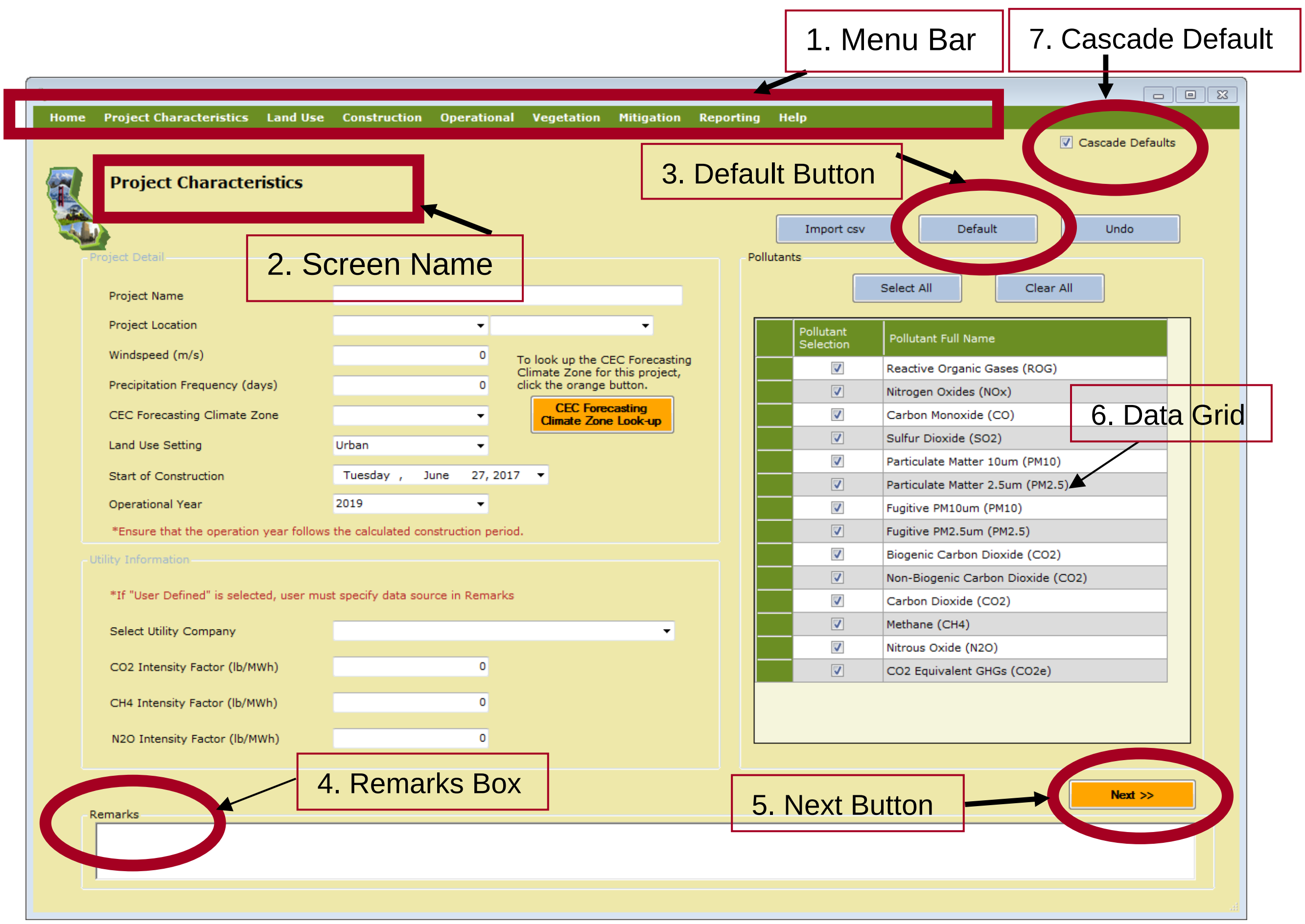
7. Cascade Defaults: CalEEMod has a feature that freezes the automatic downloading of the programmed defaults. Each input screen displays a box called Cascade Default which will be automatically checked to populate defaults in future screens. However, if user unchecks the Cascade Default box, no defaults will be populated in subsequent screens and the user will need to input project-specific data. Unless all the necessary input parameters required for a proper analysis are known, the user should run the model at least once with "Cascade Default" button checked to allow the defaults to be populated. Then, if the user would like to change the project's parameters (e.g., number of dwelling units, building square footage, etc.) without cascading new defaults in later screens, then the user should uncheck the Cascade Default box when in the Land Use screen. This feature may be helpful when the defaults are replaced with project-specific information (e.g., construction schedule, construction equipment, water use, energy use, etc.) and the user would like to evaluate different project scenarios with the same basic project information (e.g., land use type, location, etc.). In addition, by unchecking the Cascade Default box, the following will occur:

   - The defaults in *ALL* subsequent screens will be frozen.
   - Any changes that are made to screens that follow the Land Use screen (e.g., adding a new construction phase) will not cascade defaults relating to that change or add

new tabs (e.g., trips and VMT, dust material movement). Thus, the user will need to manually input project-specific information in order for the impacts to be calculated.

- If any changes to land use type (e.g., from single family housing to a hospital) are made, the subsequent screens will not reflect the new land use type causing some incorrect calculations (e.g., impacts from energy and water use) to be performed.

When changing or adding a land use type, the user should click on the Cascade Default button so the future screens will be populated with appropriate defaults and the correct calculations specific to the changed or added land use type will occur.



3.2 Home

The Home tab on the file menu bar that controls the file saving and opening features. The available options are:

- New Project
- Open Project
- Save
- Save As
- Exit

The user should select Open Project to open a project that has been previously created and saved or New Project to create a new project. Note that opening a previously saved project will remove any information that has been entered into the GUI unless it has been saved to a file. Save will save the currently loaded project database as a Microsoft Excel file and this file can be closed, and then re-opened later. Save As will allow the user to change the name of the saved project file. Exit will close CalEEMod. The Microsoft Excel file can be edited following the format of the save file to quickly make edits outside of the Graphical User Interface (GUI) but the user will still need to use the GUI in order to report the results. This can be most useful in making changes to construction lists. Data for individual tabs can be uploaded as a .csv file in various places in CalEEMod to minimize the data entry.

3.3 Defining a Project

In order to define a project, the user will need to enter information on both the Project Characteristics screen and the Land Use screen. After entering information on these two screens, CalEEMod will populate all of the other information required to calculate unmitigated construction (unless there is demolition, grading, or site preparation) and operation emissions using default data. If demolition, grading, and/or site preparation activities are part of the project, then the user will need to enter additional information on the appropriate construction screens, including but not limited to, the amount of material to be demolished and transported to or from the site. If site-specific information is not needed for the project, the user can skip this part and jump to the Mitigation screen and enter mitigation measures. After completing the Mitigation screen, the user can proceed to the Reporting screen to select the type of report to be generated for the project.

3.4 Altering Default Data

CalEEMod was designed with default assumptions supported by substantial evidence to the extent available at the time of programming. The functionality and content of CalEEMod is based on fully adopted methods and data. However, CalEEMod was also designed to allow the user to change the defaults to reflect site- or project-specific information, when available, provided that the information is supported by substantial evidence as required by CEQA. If the user chooses to modify any defaults, an explanation will be required in the Remarks box found at the bottom of the screen to justify and support the modification before the user will be able to proceed to the next screen. Modifications to defaults and the explanations are noted in the output report. Comments in the Remarks box are also included in the report and alert reviewers of modifications to the defaults. Comments are important because they show the user's justification for the modifications, which allows the reviewers the ability to determine whether or not the modifications are appropriate and sufficiently justified.

3.5 Mitigation

Common construction mitigation measures that impact the calculations in CalEEMod have been incorporated as options for the user to select. It is important to note that compliance with fugitive dust rules vary widely by district and include requirements to reduce dust. Even though the fugitive dust rules contain requirements that when implemented, have the effect of mitigating dust emissions, these requirements are not considered to be mitigation per se. For these reasons, requirements such as percentage adjustments to fugitive dust rules have not been incorporated into the unmitigated fugitive dust calculations.

Several mitigation measures from CAPCOA's Quantifying Greenhouse Mitigation Measures have been incorporated including combinations and caps when using multiple mitigation measures. CalEEMod was designed to include typical mitigation measures that are some of the more effective measures available to development projects. If mitigation measures are not available as options in CalEEMod, the user can alter the inputs in the program to adjust to account for mitigation measures that may be less common. This will require separate runs of CalEEMod files in order to properly account for unmitigated and mitigated scenarios. For more details regarding mitigation, see Subchapter 4.11.

3.6 Reporting

The Reporting tab allows the user to select the type of report (e.g., annual, winter or summer) to present the results of the calculations. The reports can be viewed on screen and then saved as either a Microsoft Excel file or a .pdf file. For more details regarding reporting, see Subchapter 4.11.

4 Detailed Program Screens

4.1 Project Characteristics

The Project Characteristics screen is starting point where the user enters the project name, project location, and selects utility provider, climate zone, and pollutants to be analyzed. The information entered on this screen will trigger project appropriate default data to populate subsequent screens. Any changes entered on this screen will override any previously entered user-defined data and the corresponding default data. The project name will appear in the reports. Each of the information categories on this screen are described in more detail below.

Project Location

To define the region where the project is located, the user is given the option to select Air District, Air Basin, County, or Statewide. The second drop down box will reveal a list of specific locations to the region selected. If the user selects County, It is important to note that there may be some counties that are shared by multiple Air Districts, Air Basins or District-specific sub-regions and the default values (e.g., on-road vehicle emissions, trip lengths, water supply and treatment electricity use, solid waste disposal rates, amount of paved roads, days of landscaping equipment use, architectural coating emissions, and hearth usage) may vary accordingly. Thus, if the user selects County, the user may also be prompted to select the sub-county area. If you are uncertain about what region to choose for your project location, consult your lead agency.

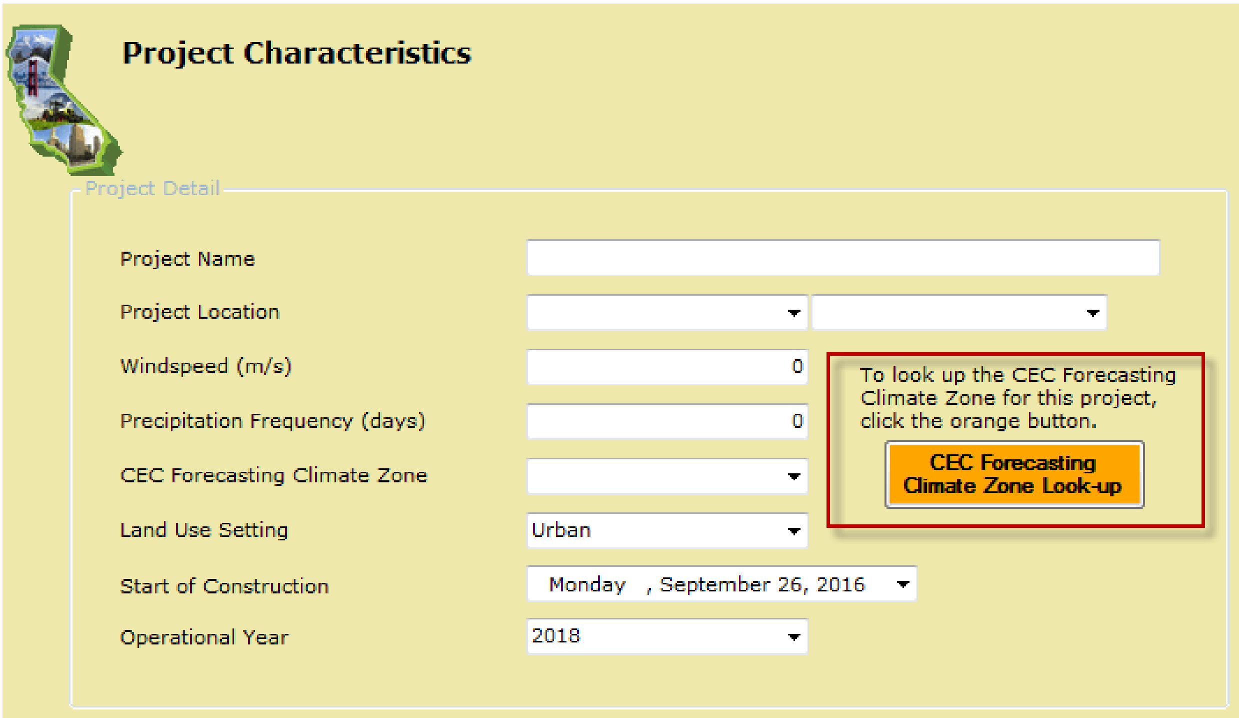
Wind Speed and Precipitation Frequency

Selection of project location will automatically fill in the default wind speed and precipitation frequency. The user can also choose to override this information and enter a different value. The wind speed, in meters per second (m/s), is used in the fugitive dust calculations. Precipitation frequency, e.g. the number of days per year with a precipitation amount measuring greater than 0.01 inches in one day, is used in the fugitive dust calculations.

Climate Zone

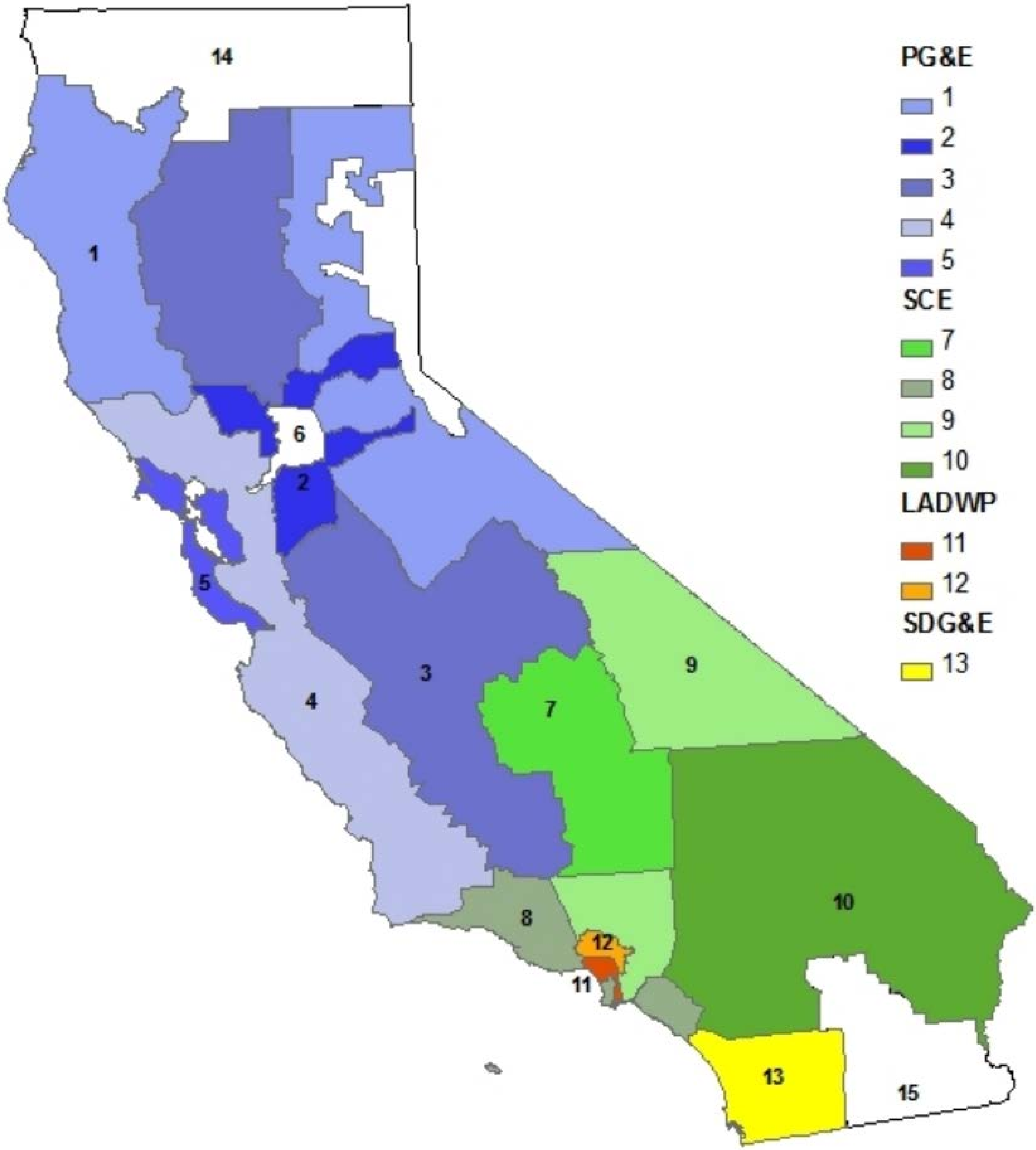
Selection of project location will restrict the climate zones available for the user to choose from based on the climate zones in the project location. The climate zones that have been programmed into CalEEMod are based on the California Energy Commission's (CEC) Forecasting Climate Zones, which are different from the Title 24 Building Climate Zones. The user should determine the correct climate zone by either referring to the figure below or by clicking on the orange button that says "CEC Climate Zone Forecasting Look-up" on the Project Characteristics screen. In addition, the user may also determine the climate zone by city or zip code from the look up tables in Appendix F.

CEC Forecasting Climate Zone Look-up Button



CalEEMod utilizes the Forecasting Climate Zones because the baseline data in the 2002 California Commercial End Use Survey (CEUS) and 2009 Residential Appliance Saturation Survey (RASS), upon which CalEEMod relies, are categorized in this manner. Further information on the calculation of building energy usage, including the application of data specific to the Forecasting Climate Zones, is contained in Appendix E.

CEC Forecasting Climate Zones[4, 5]



[4] Adapted from Figure ES-2 of CEC. 2010. Residential Appliance Saturation Survey. Available at: http://www.energy.ca.gov/2010publications/CEC-200-2010-004/CEC-200-2010-004-ES.PDF
[5] White spaces represent areas served by other electric utilities not included in survey.

Land Use Setting

The Land Use Setting tab is where the user indicates whether the project is located in a rural or urban setting. The user should contact the local air district for the region where the project is located for guidance on the appropriate Land Use Setting to select.

Start of Construction

To indicate when construction of the project will begin, the user will need to insert a date in the Start of Construction field. The date when construction will start triggers a rolling calendar that starts with the construction start date and follows by various construction phases that will be populated with default date ranges in the Construction screen.

Operational Year

CalEEMod is currently designed to key off of one year to initiate the beginning of the full operation of the project. Thus, to indicate when the project will begin operation activities, the user will need to insert a year. CalEEMod will use this year to determine the appropriate emission factors to be used in all operational module calculations. CalEEMod can accommodate the following years for the initial operational year: 2000, 2005, 2010-2035, 2040, 2045, and 2050. To conduct a backcasting analysis by inserting an operational year that occurs in the past, the selection of years is limited to minimize the file size associated with vehicle emission factors. For a project that consists of multiple phases with operation activities occurring over multiple years, the user should run the model multiple times for the various input parameters for each operational year.

Utility Company

From the drop down list, the user will need to select the appropriate utility company that will serve the project location. . When a specific utility is selected, the intensity factors for CO_2, CH_4 and N_2O will be automatically populated with defaults applicable to the specified utility. However, if the utility for the project is not in the drop down list, the user may select User Defined and the user will need to manually enter the various intensity factors. In addition, the user will need to identify the utility in the Remarks section.

The intensity factors are used in various modules to calculate the GHG emissions associated with electricity use. The default values are based on CARB's Local Government Operations Protocol (LGO)[6] for CO_2, updated public utility protocols for CO_2, and E-Grid values for CH_4 and N_2O. Each default CO_2 intensity factor is based on the latest reporting year available for each utility. Appendix D, Table 1.2 provides the default CO_2 intensity factor and reporting year from which the factor was identified for each utility identified in the drop down list. As with other defaults in the model, if a new intensity factor is identified before the defaults in CalEEMod are updated, the user may override the default and provide justification for the change in the Remarks section at the bottom of the Project Characteristics screen.

[6] Available at: http://www.arb.ca.gov/cc/protocols/localgov/localgov.htm

Pollutants

CalEEMod provides a list of pollutants with adjacent check boxes for the user to select. Upon starting a new project, all of the boxes are automatically checked and if the boxes remain checked, all pollutants will be quantified and identified in the reports. If user unchecks any of the boxes, the unchecked pollutants will be excluded from the calculations and the reports. Some of the pollutants may overlap other identified pollutants. For example, carbon dioxide (CO_2) is identified on its own, and it is separated into biogenic and non-biogenic categories. In addition, CO_2 Equivalent GHGs represents, all CO_2 emissions plus methane (CH_4) and nitrous oxide (N_2O) as adjusted by their corresponding Global Warming Potential (GWP) weighted value. The GWPs are based on the 2007 IPCC's Fourth Assessment Report (AR4)[7], and are consistent with 2014 CARB's Scoping Plan Update[8].

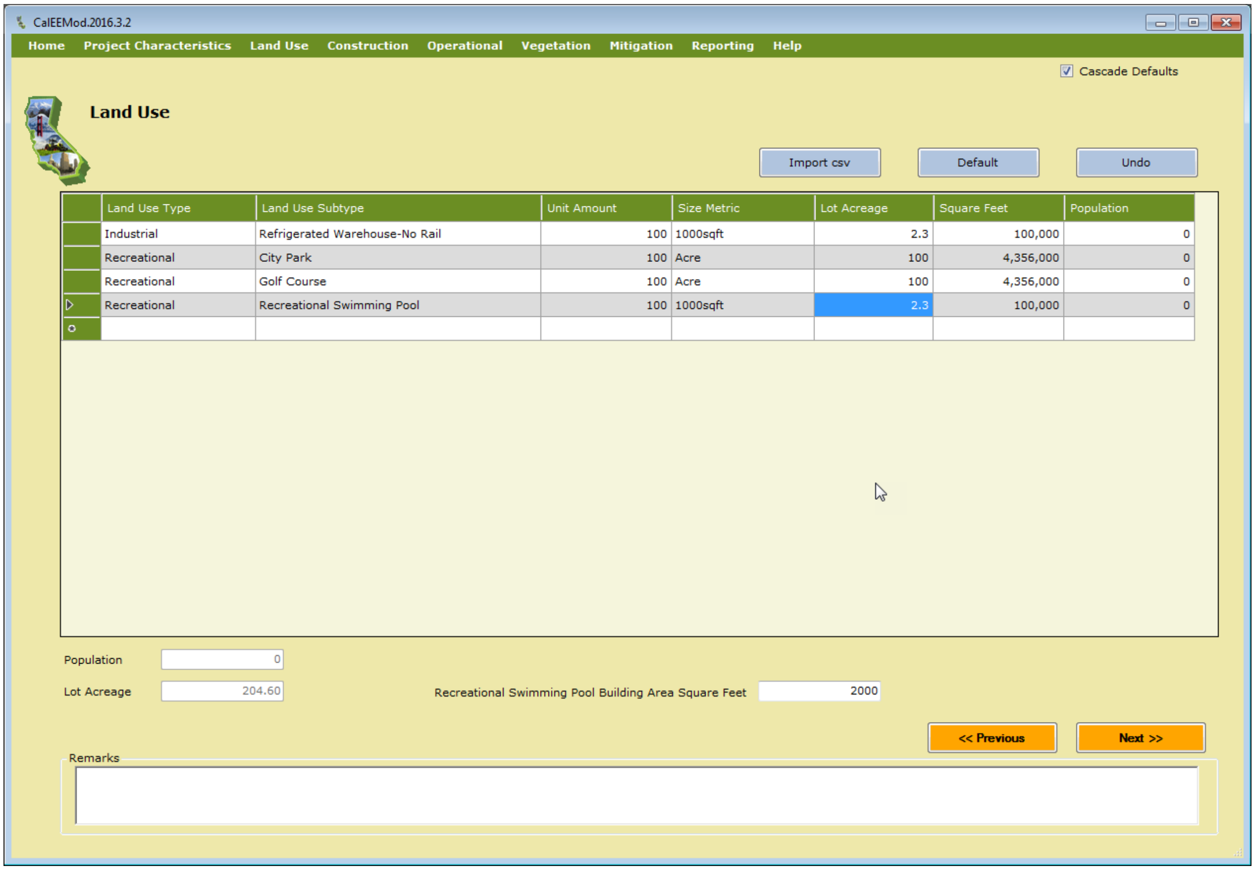
Remarks

As previously explained in Subchapter 3.4, if the user chooses to modify any defaults, the user will be required to provide an explanation or justification in the Remarks section for incorporating user defined (e.g., non-default) values before the user will be able to proceed to the next screen. Any remarks that are entered will be included in the reports and will assist a reviewer in understanding the reasons for a change in the default value (e.g., new trip rate based on a project-specific traffic study conducted by traffic engineers).

4.2 Land Use

The Land Use screen is where the user identifies the land use(s) that will occur at the project site. The data in the land use types and subtypes, unit amounts, size metric, lot acreage, square feet and population fields determine the default variables that are used in the calculations. It is important to note that for any project that includes a city park, golf course, or recreational swimming pool land use, the user will be prompted to enter the square footage of the buildings associated with these land uses (e.g., restrooms/changing rooms, pro-shop, etc.). By excluding the entire lot size for these three land use types, and instead only using the square footage of the buildings, the calculations for consumer product use will provide a more accurate representation of where these materials are actually used and avoid incorrectly attributing consumer products use to greenspaces and pool water. For more information on the calculations for consumer product use, see Subchapter 4.5, Section 4.5.2.

7 Available at: https://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_full_report.pdf
8 Available at: http://www.arb.ca.gov/cc/scopingplan/document/updatedscopingplan2013.htm


CalEEMod.2016.3.2
Home
Project Characteristics
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Unit Amount
Size Metric
Lot Acreage
Square Feet
Population
Industrial
Refrigerated Warehouse-No Rail
100
1000sqft
2.3
100,000
0
Recreational
City Park
100
Acre
100
4,356,000
0
Recreational
Golf Course
100
Acre
100
4,356,000
0
Recreational
Recreational Swimming Pool
100
1000sqft
2.3
100,000
0
Population
0
Lot Acreage
204.60
Recreational Swimming Pool Building Area Square Feet
2000
<< Previous
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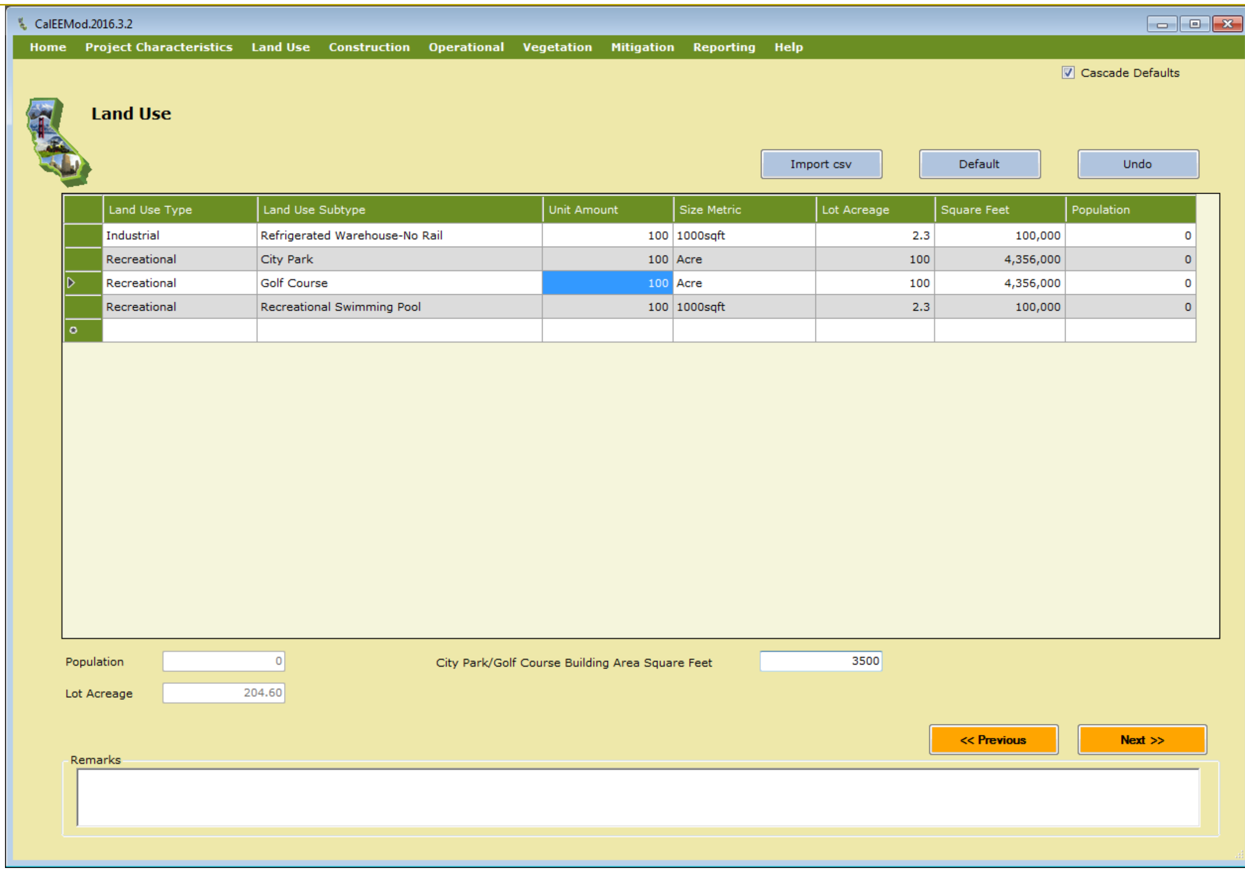
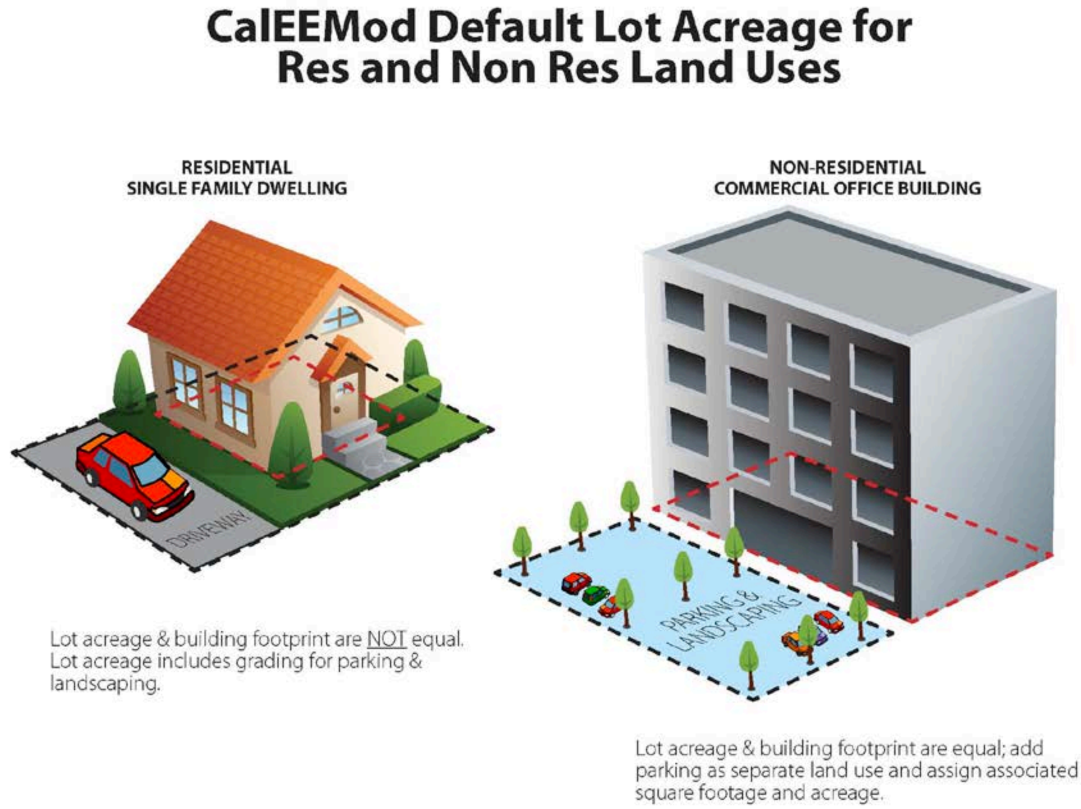
Remarks



Land Use Type

The Land Use Type tab allows the user to select any of the following primary land use types from a drop down list: Commercial, Educational, Industrial, Parking, Recreational, Residential, and Retail. The 63 different land use types were chosen for inclusion in CalEEMod because each has an established trip rate critical for mobile source calculations.

CalEEMod specifically designates parking areas as a separate land use rather than as a part of an associated non-residential land use (e.g., commercial buildings, retail facilities, etc.). However, no separate parking land use for a driveway or garage needs to be identified for residential land uses because parking is already included in the calculation For more information on how CalEEMod treats parking based on the footprint and lot acreage of residential and non-residential land uses, please refer to the following figure. As depicted, the lot acreage of a residential land use includes the parking and building footprint. For non-residential land uses, the lot acreage is the same as the building footprint, so parking needs to be entered as a separate land use.



For the parking land use subtype, two primary options are available: parking lot or parking structure (e.g., garage). There are four types of parking structures: 1) enclosed; 2) enclosed with an elevator; 3) unenclosed; and, 4) unenclosed with an elevator. The reason for these specific descriptions is so that the model properly accounts for energy impacts associated with ventilation and elevator operations.

For land use subtypes that are not listed (e.g., roads, underground parking, pipelines, etc.) or that do not accurately represent the project being analyzed, each land use subtype has a User Defined option that the user can select. If a User Defined land use subtype is selected, there is no default data (including size metric) that will automatically populate the data fields. Instead, the user will need to manually enter the unit amount, size metric, lot acreage, etc. If these fields are left blank, no emissions will be calculated for the User Defined land use subtype. Also, whatever size metric (e.g., per acre, per 1000 square foot, etc.) the user chooses for the User Defined land use subtype needs to be consistently applied to all subsequent default values (e.g., gallons of water used *per acre* or *per 1000 square foot*). An alternative approach to entering a User Defined land use subtype would be to choose a land use subtype that most closely fits the project and allow the model to populate the data fields with the defaults. Then, the user can go back through the model and modify the defaults with any known specific project information and enter the required Remarks to explain why the defaults are modified.

Land Use Subtype

63 land use subtypes have been included in CalEEMod and each has an established trip rate that is used for calculating mobile source emissions. By tabbing over to the next column in a row, the user can select a variety of land use subtypes. The user also has the option to select a User Defined land use subtype; however, as explained previously, there is no default data (including size metric) that will automatically populate the data fields. Instead, the user will need to manually enter the unit amount, size metric, lot acreage, etc. Land use subtypes are based primarily on the land use definitions used for (mobile source) trip generation rate information from the Institute of Transportation Engineers (ITE) 9th edition of the Trip Generation Manual. In some cases similar generalized land uses or surrogate data was mapped to some land use subtypes in order to generate the default data needed for various modules.

Table 1: Land Use Subtype Descriptions

Land Use Subtype	Description[1]	ITE Number
	RESIDENTIAL	
Apartments High Rise	High-rise apartments are units located in rental buildings that have more than 10 levels and most likely have one or more elevators.	222
Apartments Low Rise	Low-rise apartments are units located in rental buildings that have 1-2 levels.	221
Apartments Mid Rise	Mid-rise apartments in rental buildings that have between 3 and 10 levels.	223
Condo/Townhouse	These are ownership units that have at least one other owned unit within the same building structure.	230
Condo/Townhouse High Rise	These are ownership units that have three or more levels.	232
Congregate Care (Assisted Living)	These facilities are independent living developments that provide centralized amenities such as dining, housekeeping, transportation and organized social/recreational activities. Limited medical services may or may not be provided.	253
Mobile Home Park	Mobile home parks consist of manufactured homes that are sited and installed on permanent foundations and typically have community facilities such as recreation rooms, swimming pools and laundry facilities.	240
Retirement Community	These communities provide multiple elements of senior adult living. Housing options may include various combinations of senior adult housing, congregate care, assisted living, and skilled nursing care aimed at allowing the residents to live in one community as their medical needs change.	255
Single Family Housing	All single-family detached homes on individual lots typical of a suburban subdivision	210

Table 1: Land Use Subtype Descriptions

Land Use Subtype	Description[1]	ITE Number
	EDUCATIONAL	
Day-Care Center	A day care center is a facility where care for pre-school age children is provided, normally during the daytime hours. Day care facilities generally include classrooms, offices, eating areas and playgrounds.	565
Elementary School	Elementary schools typically serve students attending kindergarten through the fifth or sixth grade. They are usually centrally located in residential communities in order to facilitate student access and have no student drivers.	520
High School	High schools serve students who have completed middle or junior high school.	530
Junior College (2Yr)	This land use includes two-year junior, community, or technical colleges.	540
Junior High School	Junior High schools serve students who have completed elementary school and have not yet entered high school.	522
Library	A library is a facility that consists of shelved books; reading rooms or areas; and sometimes meeting rooms.	590
Place Of Worship	A church is a building in which public worship services are held. A church houses an assembly hall or sanctuary; it may also house meeting rooms, classrooms and occasionally dining catering or party facilities.	560
University/College (4Yr)	This land use includes four-year universities or colleges that may or may not offer graduate programs.	550
	RECREATIONAL	
Arena	Arenas are large indoor structures in which spectator events are held. These events vary from professional ice hockey and basketball to non-sporting events such as concerts, shows, or religious services. Arenas generally have large parking facilities, except when located in or around the downtown of a large city.	460
City Park	City parks are owned and operated by a city.	411
Fast Food Restaurant W/O Drive Thru	This land use includes fast-food restaurants without drive-through windows. Patrons generally order at a cash register and pay before they eat.	933
Fast Food Restaurant With Drive Thru	This category includes fast-food restaurants with drive-through windows.	934
Golf Course	Golf courses include 9, 18, 27 and 36 hole courses. Some sites may also have driving ranges and clubhouses with a pro shop, restaurant, lounge and banquet facilities.	430
Health Club	These are privately-owned facilities that primarily focus on individual fitness or training. Typically they provide exercise classes; weightlifting, fitness and gymnastics equipment; spas; locker rooms; and small restaurants or snack bars.	492

Table 1: Land Use Subtype Descriptions

Land Use Subtype	Description[1]	ITE Number
High Turnover (Sit Down Restaurant)	This land use consists of sit-down, full-service eating establishments with turnover rates of approximately one hour or less. This type of restaurant is usually moderately priced and frequently belongs to a restaurant chain.	932
Hotel	Hotels are places of lodging that provide sleeping accommodations and supporting facilities such as restaurants; cocktail lounges; meeting and banquet rooms or convention facilities; limited recreational facilities and other retail and service shops.	310
Motel	Motels are places of lodging that provide sleeping accommodations and often a restaurant. Motels generally offer free on-site parking and provide little or no meeting space and few supporting facilities.	320
Movie Theater (No Matinee)	Movie theaters consist of audience seating, single or multiple screens and auditoriums, a lobby and a refreshment stand. Movie theaters without matinees show movies on weekday evenings and weekends only; there are no weekday daytime showings.	443
Quality Restaurant	This land use consists of high quality, full-service eating establishments with typical turnover rates of at least one hour or longer. Quality restaurants generally do not serve breakfast, some do not serve lunch; all serve dinner. This type of restaurant usually requires reservations and is generally not part of a chain. Patrons commonly wait to be seated, are served by a waiter, order from menus and pay for meals after they eat.	931
Racquet Club	These are privately-owned facilities that primarily cater to racquet sports.	491
Recreational Swimming Pool	This is a typical recreational swimming pool that may be associated with community centers, parks, swim clubs, etc.	495
	PARKING	
Enclosed Parking Structure	This is an enclosed parking structure that may be above or below ground. It is not covered in asphalt. This land use will require lighting and ventilation, and will be more than one floor with no elevator.	
Enclosed Parking with Elevator	This is an enclosed parking structure that may be above or below ground. It is not covered in asphalt. This land use will require lighting and ventilation, and will be more than one floor with an elevator.	
Other Asphalt Surfaces	This is an asphalt area not used as a parking lot (e.g., long driveway, basketball court, etc.)	
Other Non-Asphalt Surfaces	This is a non-asphalt area (e.g., equipment foundation, loading dock area, etc.).	
Parking Lot	This is a typical single surface parking lot typically covered with asphalt. This land use will require lighting.	
Unenclosed Parking Structure	This is an unenclosed parking structure that may be above or below ground. It is not covered in asphalt. This land use will require lighting but not ventilation. It will be more than one floor with no elevator.	
Unenclosed Parking with Elevator	This is an unenclosed parking structure that may be above or below ground. It is not covered in asphalt. This land use will require lighting but not ventilation. It will be more than one floor with an elevator.	

Table 1: Land Use Subtype Descriptions

Land Use Subtype	Description[1]	ITE Number
	RETAIL	
Automobile Care Center	An automobile care center houses numerous businesses that provide automobile-related services, such as repair and servicing; stereo installation; and seat cover upholstering.	942
Convenience Market (24 Hour)	These markets sell convenience foods, newspapers, magazines and often beer and wine. They do not sell or dispense motor vehicle fuels (e.g., gasoline and diesel).	851
Convenience Market With Gas Pumps	These markets sell or dispense motor vehicle fuels (e.g., gasoline and diesel), convenience foods, newspapers, magazines and often beer and wine. This includes convenience markets with motor vehicle fueling dispensers where the primary business is the selling of convenience items, not the fueling of motor vehicles.	853
Discount Club	A discount club is a discount store or warehouse where shoppers pay a membership fee in order to take advantage of discounted prices on a wide variety of items such as food, clothing, tires and appliances. Many items are sold in large quantities or in bulk.	857
Electronic Superstore	These are free-standing facilities that specialize in the sale of electronic merchandise.	863
Free-Standing Discount Store	Discount stores offer centralized cashiering and sell products that are advertised at discount prices. These stores offer a variety of customer services and maintain long store hours seven days a week.	815
Free-Standing Discount Superstore	The discount superstore is similar to the free-standing discount stores with the addition that they also contain a full-service grocery department under the same roof that shares entrances and exits with the discount store area.	813
Gasoline/Service Station	This land use includes service stations where the primary business is the fueling of motor vehicles. They may also have ancillary facilities for servicing and repairing motor vehicles.	944
Hardware/Paint Store	These stores sell hardware and paint supplies and are generally free-standing buildings.	816
Home Improvement Superstore	These are free-standing facilities that specialize in the sale of home improvement merchandise.	862
Regional Shopping Center	A shopping center is an integrated group of commercial establishments that is planned, developed, owned and managed as a unit. A shopping center's composition is related to its market area in terms of size, location and type of store.	820
Strip Mall	Small strip shopping centers contain a variety of retail shops and specialize in quality apparel, hard goods and services such as real estate offices, dance studios, florists and small restaurants.	826

Table 1: Land Use Subtype Descriptions

Land Use Subtype	Description[1]	ITE Number
Supermarket	Supermarkets are free-standing retail stores selling a complete assortment of food: food preparation and wrapping materials; and household, cleaning items. Supermarkets may also contain the following products and services: ATMs, automobile supplies, bakeries, books and magazines, dry cleaning, floral arrangements, greeting cards, limited-service banks, photo centers, pharmacies and video rental areas.	850
COMMERCIAL		
Bank (With Drive-Through)	Drive-in banks provide banking facilities for motorists who conduct financial transactions from their vehicles; many also serve patrons who walk into the building.	912
General Office Building	A general office building houses multiple tenants where affairs of businesses commercial or industrial organizations or professional persons or firms are conducted. If information is known about individual buildings, it is suggested that this land use be used instead of the more generic office park.	710
Government (Civic Center)	A group of government buildings that are interconnected by pedestrian walkways.	733
Government Office Building	This is an individual building containing either the entire function or simply one agency of a city, county, state, federal, or other governmental unit.	730
Hospital	A hospital is any institution where medical or surgical care and overnight accommodations are provided to non-ambulatory and ambulatory patients. However, it does not refer to medical clinics or nursing homes.	610
Medical Office Building	This is a facility that provides diagnoses and outpatient care on a routine basis but is unable to provide prolonged in-house medical and surgical care. One or more private physicians or dentists generally operate this type of facility.	720
Office Park	Office parks are usually suburban subdivisions or planned unit developments containing general office buildings and support services, such as banks, restaurants and service stations, arranged in a park-or campus-like atmosphere. This should be used if details on individual buildings are not available.	750
Pharmacy/Drugstore W/O Drive Thru	These are retail facilities that primarily sell prescription and non-prescription drugs. These facilities may also sell cosmetics, toiletries, medications, stationery, personal care products, limited food products and general merchandise. The drug stores in this category do not contain drive-through windows.	880

Table 1: Land Use Subtype Descriptions

Land Use Subtype	Description[1]	ITE Number
Pharmacy/Drugstore With Drive Thru	These are retail facilities that primarily sell prescription and non-prescription drugs. These facilities may also sell cosmetics, toiletries, medications, stationery, personal care products, limited food products and general merchandise. The drug stores in this category contain drive-through windows.	881
Research & Development	R&D centers are facilities devoted almost exclusively to R&D activities. The range of specific types of businesses contained in this land use category varies significantly. R&D centers may contain offices and light fabrication areas.	760
INDUSTRIAL		
General Heavy Industry	Heavy industrial facilities usually have a high number of employees per industrial plant and are generally limited to the manufacturing of large items.	120
General Light Industry	Light industrial facilities are free-standing facilities devoted to a single use. The facilities have an emphasis on activities other than manufacturing and typically have minimal office space. Typical light industrial activities include printing, material testing and assembly of data processing equipment.	110
Industrial Park	Industrial parks contain a number of industrial or related facilities. They are characterized by a mix of manufacturing, service and warehouse facilities with a wide variation in the proportion of each type of use from one location to another. Many industrial parks contain highly diversified facilities.	130
Manufacturing	Manufacturing facilities are areas where the primary activity is the conversion of raw materials or parts into finished products. It generally also has office, warehouse, and R&D functions at the site.	140
Refrigerated Warehouse-No Rail	This is a warehouse that has refrigeration but no rail spur.	152
Refrigerated Warehouse-Rail	This is a warehouse that has refrigeration and a rail spur.	152
Unrefrigerated Warehouse-No Rail	This is a warehouse that does not have refrigeration and no rail spur.	152
Unrefrigerated Warehouse-Rail	This is a warehouse that does not have refrigeration but has a rail spur.	152

[1] Based on land use descriptions in Institute of Transportation Engineers (ITE) Trip Generation Manual, 9th Edition.

Unit Amount and Size Metric

By tabbing over to the Unit Amount and Size Metric columns, respectively, the user can enter the number of units (e.g., houses, apartments, etc.) and the corresponding size metric (e.g., per 1000 sq. ft., employees, students, etc.). This data combination will be used to populate the lot acreage, square feet and population columns on this screen. For example, a school land use allows the user to define its size by the number of students, building square footage, or number of employees. It is important to note that the square footage, which is used for calculating such impacts as architectural coatings and energy use, relates to the total building square footage and not the building footprint or lot acreage which is used for housing density as well as grading and site preparation calculations.

Lot Acreage

If actual lot acreage data is available, the user should override the default value. However, for a mixed use, multi-story building, the user should not override the square footage default value for each individual land use or the acreage default value assigned to the residential portion or the split between the non-residential land uses if there is no residential portion. The figure below provides an example of a mixed use project and instructions for applying the appropriate square footage and acreage.

Acreage is used to estimate housing density and assign construction default data (e.g., grading, site preparation, etc.). Table 2 contains housing density default data per land use in terms of dwelling units (DU) per acre. By using this data, CalEEMod can estimate the number of acres per dwelling unit (DU) for residential land use. For example, if the user enters 10 apartments in a low rise building, then the lot acreage will be 0.625 acre (10 DU divided by 16 acres/DU). According to the California Energy Commission's Residential Appliance Saturation Survey (RASS), the metric for low rise apartments is 1,000 square feet per DU (see Table 2.1). Similarly, using the same example, the building footprint will be 0.23 acre (10 DU x 1000 sq. ft./DU x 1 acre/43,560 sq. ft.). Thus, the total lot acreage includes the residential footprint plus driveway and landscaping/open space.

After the user has completed entering all of land uses for the project, CalEEMod will add the lot acreage values for each land use and the total will be reflected in the lot acreage text box located at the bottom of the screen. The value in the total lot acreage box cannot be modified by the user.

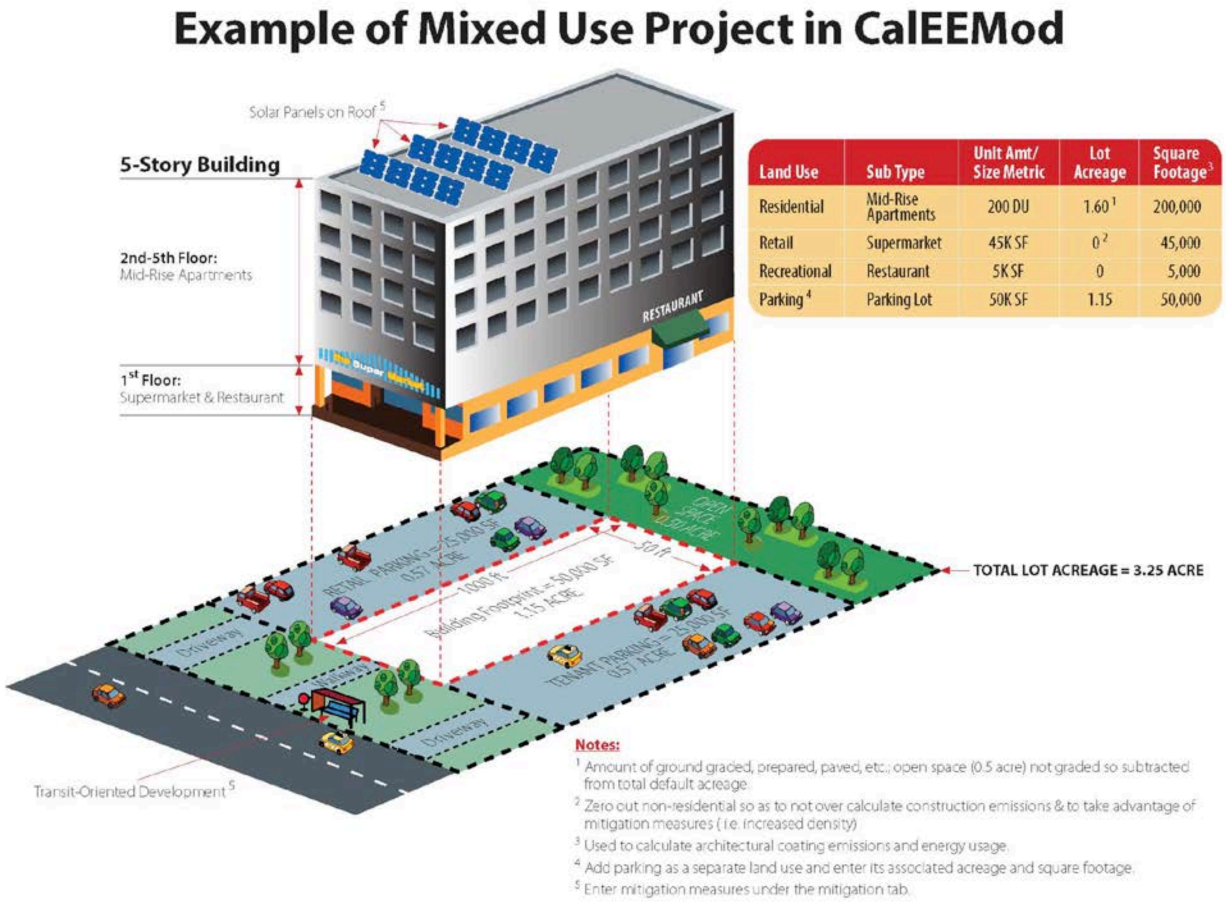


Table 2: Default Housing Density[1]

Land Use Subtype	Density (Dwelling Units/Acre)
Single Family Housing	3
Apartments low rise	16
Apartments mid rise	38
Apartments high rise	62
Condo/townhouse	16
Condo/townhouse high rise	64
Mobile Home Park	8
Retirement Community	5
Congregate care (Assisted Living)	16

[1] Based on the density assumed in ITE Trip Generation 8th Edition

Square Footage

If actual square footage of the total building or building footprint is known, the user should override the default value.

Population

After the completing the tabs for unit amount, size metric, lot acreage, and square footage, the population field will contain a default which represents an estimate of the population for each land use type and subtype selected by the user. If the actual population data is known, the user should override the default value.

After the user has completed entering all of land uses for the project, CalEEMod will add the population values for each land use and the total will be reflected in the population text box located at the bottom of the screen. The value in the total population box cannot be modified by the user.

City Park/Golf Course Building Area Square Feet (text box)

If the user selects a City Park and/or Golf Course land use, a text box will appear at the bottom of the screen that will prompt the user to enter the building square footage of all the buildings that will be located on the City Park and/or Golf Course property (e.g., restrooms/changing rooms, pro-shop, etc.). The user must input site-specific building square footage data because there are no default values for building footprints on these types of land uses. If the building square footage is left blank (e.g., zero square feet), a warning message will appear to remind the user to enter a value in this field.

Recreational Swimming Pool Building Area Square Feet (text box)

If the user selects a Recreational Swimming Pool land use, a text box will appear at the bottom of the screen that will prompt the user to enter the building square footage of all the buildings that will be located on the property (e.g., restrooms/changing rooms, pro-shop, etc.). The user must input site-specific building square footage data because there is no default value for the building footprint on this type of land use. If the building square footage is left blank (e.g., zero square feet), a warning message appear to remind the user to enter a value in this field.

4.3 Construction

After completing the Land Use screen and clicking on the Next button, the Construction screen will appear along with seven tabs/sub-screens that cover the following construction topic areas: Construction Phase; Off-Road Equipment; Dust from Material Movement; Demolition; Trips and VMT, On-Road Fugitive Dust, and Architectural Coatings. To move from one tab/subscreen to another, the user can use the Next and Previous buttons, or click on any of grey tabs. The construction tabs/sub-screens contain default information that was obtained from a survey of construction sites conducted by South Coast Air Quality Management District (SCAQMD). The construction survey data is grouped by construction phase and lot acreage and can be found in Appendix E1. The default construction equipment list and phase length data were determined to be the most appropriate for the size and types surveyed. In addition, some data in the survey was extrapolated to create default values for project sizes that were not in the survey. However, if the user has more detailed site-specific equipment and phase information, the user should override the default values.

4.3.1 Construction Phase

The Construction Phase tab is where the user can enter the type of each construction phase and the date range for each phase. . Default phases are based on the total lot acreage of the project. Depending on the project being modeled, not all phases may be necessary so the user may need to delete phases that are not applicable to the project. For example, not all projects require demolition. In addition, the user may need to add multiple phases of similar types for large projects with staged build out scenarios. It is important to note that if a project has demolition, grading, and site preparation phases, the user will need to provide additional project-specific data on the Demolition and Dust from Material Movement sub-screens.

Phase Name and Phase Type

The Phase Name and Phase Type fields will be automatically populated with the following default construction phases: Site Preparation; Demolition; Grading; Building Construction; Paving; and, Architectural Coating. The inclusion of any of these phases will define the types of calculations and default assumptions for on-road vehicle trips and fugitive emissions that occur in subsequent construction sub-screens. The definitions of the default phase types are as follows:

- *Demolition* involves removing buildings or structures.
- *Site Preparation* involves clearing vegetation (grubbing and tree/stump removal) and removing stones and other unwanted material or debris prior to grading.
- *Grading* involves the cut and fill of land to ensure that the proper base and slope is created for the foundation.
- *Building Construction* involves the construction of the foundation, structures and buildings.
- *Architectural Coating* involves the application of coatings to both the interior and exterior of buildings or structures, the painting of parking lot or parking garage striping, associated signage and curbs, and the painting of the walls or other components such as stair railings inside parking structures.
- *Paving* involves the laying of concrete or asphalt such as in parking lots, roads, driveways, or sidewalks.

Start Date and End Date

The user can enter with the aid of a calendar, the Start Date and End Dates for each construction phase. The default Start Date is the Start of Construction date defined on the Project Characteristics screen. The cells will be automatically populated with a default construction schedule starting with the Demolition phase, with subsequent phases starting the following day after the previous phase's end date. The user may change the defaults to alter the total days estimated for each phase. Because CARB's emission factors vary from year to year, when the user inserts the start and end dates for each construction phase, the model will select the correct emission factors for the year when each piece of off-road equipment will be utilized.

Days per Week

The user can select from a drop down box the number of days per week (either 5, 6, or 7 days) that construction will occur. Five days per week assumes that construction will occur from Monday through Friday, and six days per week assumes that construction will occur Monday through Saturday.

Total Days

The Total Days field is intended to indicate the number of days that it will take to complete a particular construction phase and this field is initially populated with default values. If the End Date or the Days per Week fields are changed, clicking the Total Days field will trigger a recalculation of the Total Days. If the Total Days field for any phase is changed, then once leaving this field, the program will automatically adjust the End Date based on the Start Date for that phase.

4.3.2 Off-Road Equipment

The Off-Road Equipment tab is for the user to select the type and quantity of off-road equipment needed for each construction phase and to define the daily usage schedule. Since equipment lists can be lengthy and vary widely for each construction phase, the user will need to first select the phase from Phase Name drop down list or by clicking on the Previous or Next buttons located next to the phase name, and then select the off-road equipment that will be used for each construction phase. The Off-Road Equipment screen calculates emissions based on the expected off-road equipment engine use for each piece of equipment listed over the duration of the phase length. It is important to note that fugitive emissions from off-road equipment are calculated elsewhere on other construction screens.

After the user enters the Equipment Type, Number of Units, and Hours per Day for each piece of equipment that will be used in any phase, The Horsepower and Load Factor fields will be automatically populated with the default average values from CARB's OFFROAD2011. If equipment-specific information is available, the user can override these default values. In some cases, CARB's OFFROAD2011 emission factors are not available for all years. Thus, if the user selects a construction year that does not have corresponding emission factors, CalEEMod has been programmed to substitute the emissions factors from nearest, lower end (e.g., oldest) year. For example, if construction will occur in year 2037 (a year which does not have emission factors), CalEEMod will substitute the emission factors from year 2035 instead. Since newer equipment tends to have less emissions than older equipment, by selecting emission factors from year 2035 (an older year), the calculations may result in a conservative, slight overestimate of emissions.

If the project requires the use of off-road equipment that is not specifically listed in the drop down list, the user can select from three generalized equipment categories to add customized equipment to the analysis: 1) Other Construction Equipment; 2) Other General Industrial Equipment; and, 3) Other Material Handling Equipment. In addition, the user may choose to select a surrogate equipment type which has a similar horsepower rating and load factor. To include water trucks and cement trucks in the analysis, the user needs to first determine if these trucks are off-road or on-road vehicles. If they are only driven off-road, then the user can select the Off-Highway Trucks category in the Off-Road Equipment screen. If the trucks are driven on-road, the user can account for the on-road emissions by entering this information as Additional Vendor Trips on the Trips and VMT screen (see Subchapter 4.3.5).

4.3.3 Dust from Material Movement

The Dust from Material Movement sub-screen is intended for calculating fugitive dust emissions associated with the Site Preparation and Grading phases (defaults) during construction. This sub-screen calculates the following three types of fugitive dust: 1) fugitive dust from dozers moving dirt; 2) fugitive dust from graders or scrapers leveling the land; and; 3) fugitive dust from loading or unloading dirt into haul trucks. These methods have been adapted from USEPA's AP-42 method for Western Coal Mining. Once the enters the amount of material imported and exported to the site, CalEEMod will estimate the number of hauling trips associated with from material transport activities. The user may define the units in terms of Ton of Debris or Cubic Yards. The user may also select whether the import/export of material is phased (e.g., a the same truck that arrives with material departs with another load of material to export in one round trip or two-one way trips. The calculations for non-phased material import/export trips assume that one truck arrives empty and departs full and a different truck arrives full for a total of two round trips (or four one-way trips). Thus, phasing material import and export trips reduces the number of haul trips.

The Total Acres Graded field represents the cumulative distance traversed on the property by the grading equipment, assuming a blade width of 12 feet. In order to properly grade a piece of land, multiple passes with grading equipment may be required. So even though the lot size is a fixed number of acres, the Total Acres Graded could be an order of magnitude higher than the footprint of the lot and is calculated based on the equipment list (including number of equipment), the number of days need to complete the grading and/or site preparation phase, and the maximum number of acres a given piece of equipment can traverse in an 8-hour workday. For more information regarding how Dust from Material Movement is calculated, including grading rates, see Appendix A, Subchapter 4.3.

4.3.4 Demolition

The Demolition sub-screen is intended for the user to enter the amount of material that is demolished, if a demolition phase is selected by the user as part of the construction project. The user can select the Size Metric to define the amount of demolished material that is expected to be generated during the demolition phase in terms of Ton of Debris or Building Square Footage. With this data, fugitive dust emissions generated during demolition are calculated. The calculation of fugitive dust emissions during demolition is derived from the methodology described in the report prepared for the USEPA by Midwest Research Institute, Gap Filling PM_{10} Emission Factors for Selected Open Area Dust Sources.

4.3.5 Trip and VMT

The Trip and VMT sub-screen is used to provide the number and length (in terms of vehicle miles traveled or VMT) of on-road vehicle trips for workers, vendors, and hauling for each construction phase. Depending on the land use type and subtype combined with the various construction phases, CalEEMod will populate the fields for Number of Trips, Trip Length, and Vehicle Class for worker, vendor and haul trips, respectively, with default values. The vehicle class descriptor HHDT, MHDT means that there is a 50/50 percent mix of heavy-heavy duty trucks and medium-heavy duty trucks. Similarly, the vehicle class descriptor LDA, LDT1, LDT2 means that there is a 50/25/25 percent mix of light duty autos, light duty truck class 1 and light duty truck class 2, respectively. The user may override the defaults and enter different weightings of vehicle fleet mixes. It is important to note that if the user selects a construction year that does not have corresponding EMFAC2014 emission factors for on-road vehicles, CalEEMod has been programmed to substitute the emissions factors from nearest, lower end (e.g., oldest) year. For example, if construction will occur in year 2037 (a year which does not have emission factors), CalEEMod will substitute the emission factors from year 2035 instead. Since newer equipment tends to have less emissions than older equipment, by selecting emission factors from year 2035 (an older year), the calculations may result in a conservative, slight overestimate of emissions.

CalEEMod quantifies the number of construction workers by multiplying 1.25 times the number of pieces of equipment for all phases (except Building Construction and Architectural Coating). For the Building Construction, the number of workers is derived from a study conducted by the Sacramento Metropolitan Air Quality Management District (SMAQMD) which determined the number of workers needed for various types of land uses and corresponding project size. This study and its analysis are included in Appendix E2. For the Architectural Coating phase, the number of workers is approximately 20% of the number of workers needed during the Building Construction phase.

The number of vendor trips during the Building Construction phase is also derived from a study conducted by the SMAQMD. The SMAQMD trip survey during construction counted cement and water trucks as vendor trips (instead of counting them as off-road vehicle trips) and these trip rates were incorporated into the calculations for the Building Construction phase. If the user deletes the Building Construction phase from the analysis, but the project will require water and/or cement trucks, then the user will need to account for these either as vendor trips under another construction phase or under the Off-Road equipment screen.

The default values for hauling trips are based on the assumption that a truck can haul 20 tons (or 16 cubic yards) of material per load. If one load of material is delivered, CalEEMod assumes that one haul truck importing material will also have a return trip with an empty truck (e.g., 2 one-way trips). Similarly, a haul truck needed to export material is assumed to have an arrival trip in an empty truck and a loaded departure truck (e.g., 2 one-way trips). Thus, each trip to import and export material is considered as two separate round trips (or 4 one-way trips). However, if the Phase box is checked, the same haul truck that imported the material will be assumed to be the same haul truck that export material resulting in one round trip (or 2 one-way trips).

4.3.6 On-Road Fugitive Dust

The On-Road Fugitive Dust sub-screen defines the variables that will be used to determine the fugitive dust emissions from on-road vehicles driving over paved and unpaved roads during construction. CalEEMod automatically populates the data fields based on the construction phase. The calculations use emission factors from USEPA's AP-42 for paved roads (January 2011 edition) and unpaved roads (November 2006 edition). Each data field is the same as those defined in the aforementioned AP-42 sections.

4.3.7 Architectural Coatings

The Architectural Coatings sub-screen is intended to calculate ROG emissions associated with painting the interior/exterior of residential and non-residential buildings as well as calculate emissions from parking lot painting or striping. The user may override any of the default interior and exterior surface areas estimated for residential and non-residential buildings. In addition, each of these surface types has a different emission factor indicating the ROG content of the paint in grams per liter (g/L). It is important to note that the parking area square footage is not included in the non-residential interior/exterior square footage when calculating emissions attributable to parking lot striping. See Appendix A, Subchapter 4.7 for the methodology of estimating surface areas to be coated from building square footage.

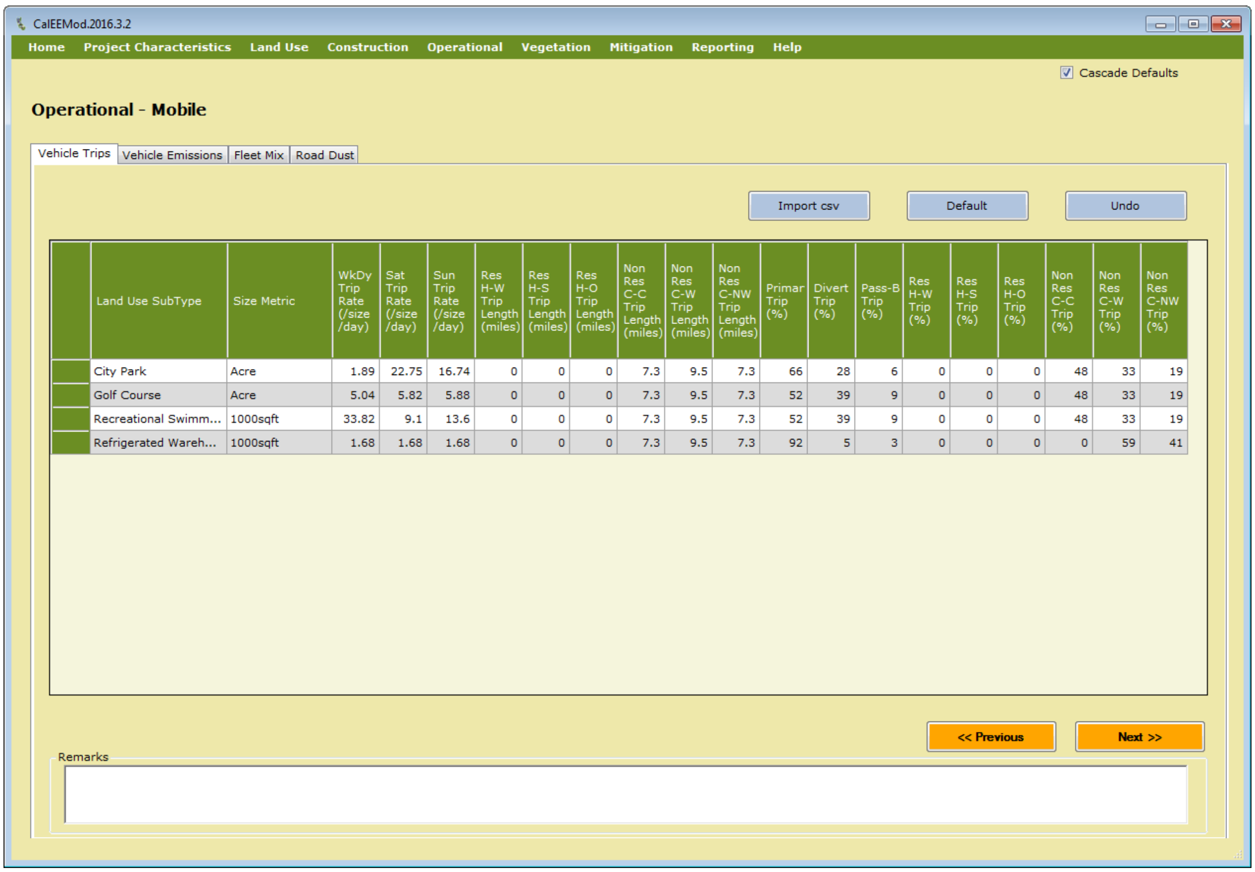
4.4 Operational Mobile

The operational mobile screen is made up of four sub-screens: Vehicle Trips, Vehicle Emissions, Fleet Mix and Road Dust. These screens are used in defining the information necessary to calculate the emissions associated with operational on-road vehicles.

4.4.1 Vehicle Trips

This sub-screen includes the trip rates, trip lengths, trip purpose, and trip type percentages for each land use subtype in the project. The user can edit any of this information by entering a new value in the appropriate cell. Trip rates are in terms of the size metric (thousand square footage or dwelling unit) defined on the land use screen and are listed for weekday, Saturday and Sunday if available. Trip lengths are for primary trips. Trip purposes are primary, diverted, and pass-by trips. Diverted trips are assumed to take a slightly different path than a primary trip and are assumed to be 25% of the primary trip lengths. Pass-by trips are assumed to be 0.1 miles in length and are a result of no diversion from the primary route. Residential trip types are defined as home-work (H-W), home-shop (H-S), and home-other (H-O). Non-residential trip types are defined as commercial –customer (C-C), commercial-work (C-W), and commercial-nonwork (C-NW) such as delivery trips. Appendix A includes the equations and methodology used to calculate motor vehicle emissions from the operation of a project.

The trip rates are based on ITE 9th edition average trip rates for the respective land use categories.

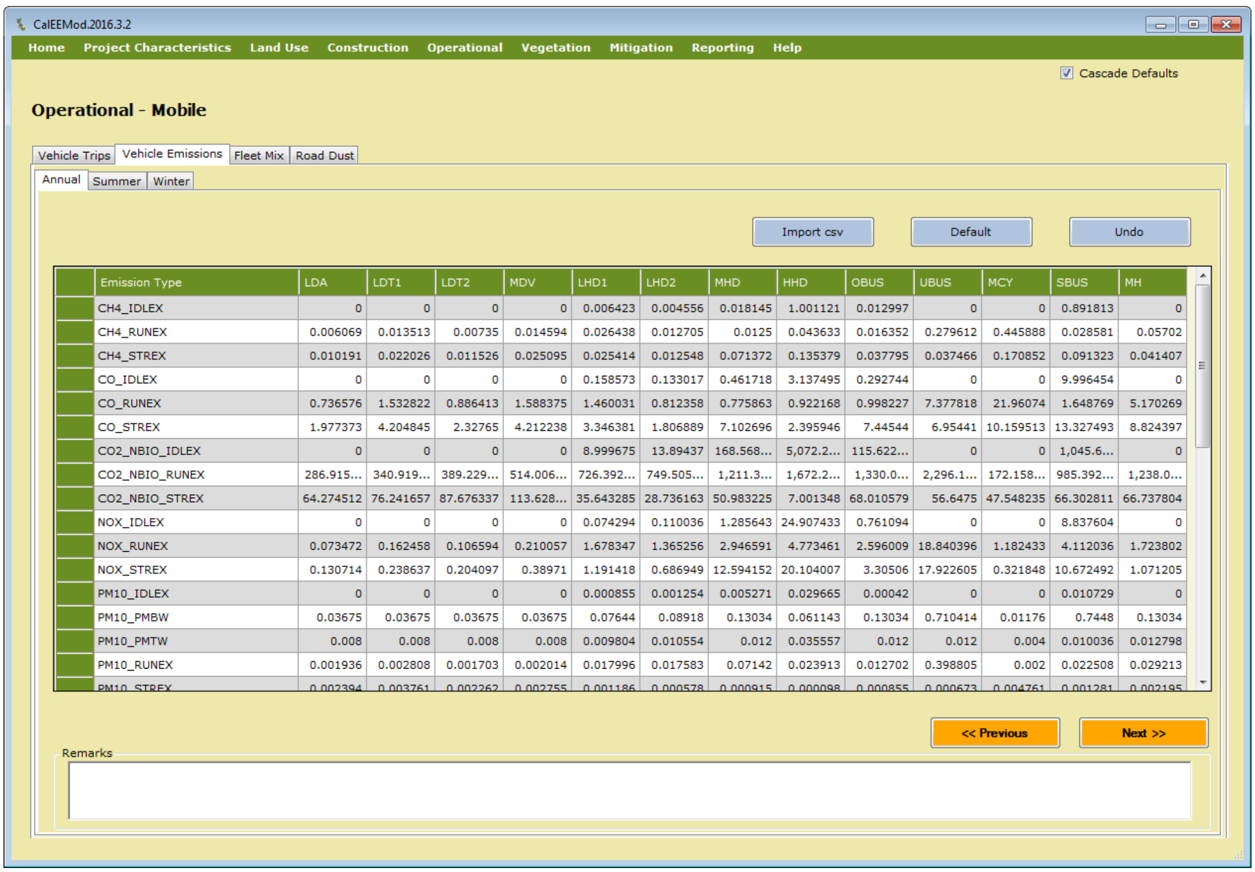


Land Use SubType	Size Metric	WkDy Trip Rate (/size /day)	Sat Trip Rate (/size /day)	Sun Trip Rate (/size /day)	Res H-W Trip Length (miles)	Res H-S Trip Length (miles)	Res H-O Trip Length (miles)	Non Res C-C Trip Length (miles)	Non Res C-W Trip Length (miles)	Non Res C-NW Trip Length (miles)	Primar Trip (%)	Divert Trip (%)	Pass-B Trip (%)	Res H-W Trip (%)	Res H-S Trip (%)	Res H-O Trip (%)	Non Res C-C Trip (%)	Non Res C-W Trip (%)	Non Res C-NW Trip (%)
City Park	Acre	1.89	22.75	16.74	0	0	0	7.3	9.5	7.3	66	28	6	0	0	0	48	33	19
Golf Course	Acre	5.04	5.82	5.88	0	0	0	7.3	9.5	7.3	52	39	9	0	0	0	48	33	19
Recreational Swimm...	1000sqft	33.82	9.1	13.6	0	0	0	7.3	9.5	7.3	52	39	9	0	0	0	48	33	19
Refrigerated Wareh...	1000sqft	1.68	1.68	1.68	0	0	0	7.3	9.5	7.3	92	5	3	0	0	0	0	59	41

4.4.2 Vehicle Emissions

This sub-screen contains the detailed vehicle emission factors based on EMFAC2014. Appendix A includes the description of how these emission factors were derived from EMFAC2014. It is anticipated that most users will not edit data in this sub-screen. There are separate tabs for annual, summer, and winter emissions values. If the user wants to alter the breakdown of fuel types (catalytic, non-catalytic, and other) within a vehicle class, they will have to provide their own data. This will likely be an infrequent change due to CEQA enforceability requirements.

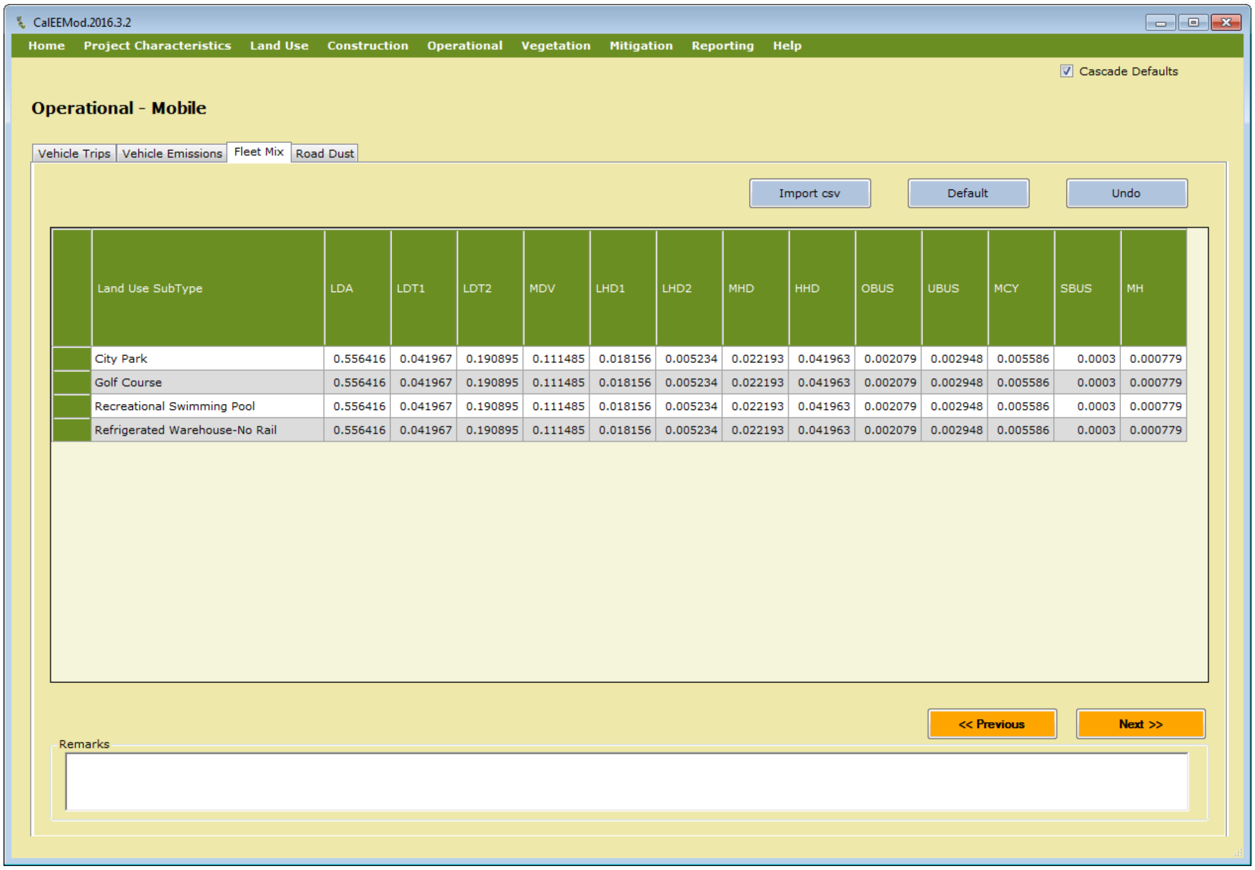
This screen along with the previous screen (Vehicle Trips) and next screen (Fleet Mix) will provide the data for the model to calculate the emissions associated with on-road motor vehicle use. The calculation does not include the fugitive dust emissions from travel over roads as these are associated with the next screen (Road Dust).



Emission Type	LDA	LDT1	LDT2	MDV	LHD1	LHD2	MHD	HHD	OBUS	UBUS	MCY	SBUS	MH
CH4_IDLEX	0	0	0	0	0.006423	0.004556	0.018145	1.001121	0.012997	0	0	0.891813	0
CH4_RUNEX	0.006069	0.013513	0.00735	0.014594	0.026438	0.012705	0.0125	0.043633	0.016352	0.279612	0.445888	0.028581	0.05702
CH4_STREX	0.010191	0.022026	0.011526	0.025095	0.025414	0.012548	0.071372	0.135379	0.037795	0.037466	0.170852	0.091323	0.041407
CO_IDLEX	0	0	0	0	0.158573	0.133017	0.461718	3.137495	0.292744	0	0	9.996454	0
CO_RUNEX	0.736576	1.532822	0.886413	1.588375	1.460031	0.812358	0.775863	0.922168	0.998227	7.377818	21.96074	1.648769	5.170269
CO_STREX	1.977373	4.204845	2.32765	4.212238	3.346381	1.806889	7.102696	2.395946	7.44544	6.95441	10.159513	13.327493	8.824397
CO2_NBIO_IDLEX	0	0	0	0	8.999675	13.89437	168.568...	5,072.2...	115.622...	0	0	1,045.6...	0
CO2_NBIO_RUNEX	286.915...	340.919...	389.229...	514.006...	726.392...	749.505...	1,211.3...	1,672.2...	1,330.0...	2,296.1...	172.158...	985.392...	1,238.0...
CO2_NBIO_STREX	64.274512	76.241657	87.676337	113.628...	35.643285	28.736163	50.983225	7.001348	68.010579	56.6475	47.548235	66.302811	66.737804
NOX_IDLEX	0	0	0	0	0.074294	0.110036	1.285643	24.907433	0.761094	0	0	8.837604	0
NOX_RUNEX	0.073472	0.162458	0.106594	0.210057	1.678347	1.365256	2.946591	4.773461	2.596009	18.840396	1.182433	4.112036	1.723802
NOX_STREX	0.130714	0.238637	0.204097	0.38971	1.191418	0.686949	12.594152	20.104007	3.30506	17.922605	0.321848	10.672492	1.071205
PM10_IDLEX	0	0	0	0	0.000855	0.001254	0.005271	0.029665	0.00042	0	0	0.010729	0
PM10_PMBW	0.03675	0.03675	0.03675	0.03675	0.07644	0.08918	0.13034	0.061143	0.13034	0.710414	0.01176	0.7448	0.13034
PM10_PMTW	0.008	0.008	0.008	0.008	0.009804	0.010554	0.012	0.035557	0.012	0.012	0.004	0.010036	0.012798
PM10_RUNEX	0.001936	0.002808	0.001703	0.002014	0.017996	0.017583	0.07142	0.023913	0.012702	0.398805	0.002	0.022508	0.029213
PM10_STREX	0.002394	0.003761	0.002262	0.002755	0.001186	0.000578	0.000915	0.000098	0.000855	0.000673	0.004761	0.001281	0.002195

4.4.3 Fleet Mix

In CalEEMod Version 2016.3.1, the fleet mix was separated from the Vehicle Emissions screen and a new Fleet Mix screen was created so that users are able to change default fleet mix associated with different land use subtypes.



4.4.4 Road Dust

This sub-screen is used to change any of the default values that are used in the USEPA's AP-42 methods for calculating fugitive emissions from paved and unpaved roads. The defaults for the road dust (e.g., material silt content, material moisture content, and mean vehicle speed) are statewide averages, but the user has the ability to override the defaults if data specific to the project is known. Local jurisdictions can also provide guidance to users as to what default properly reflects known regional road dust parameters.

For the San Luis Obispo region, the user is recommended to provide the following unpaved road dust parameters overriding the statewide defaults if users choose to use USEPA's AP-42 methods:

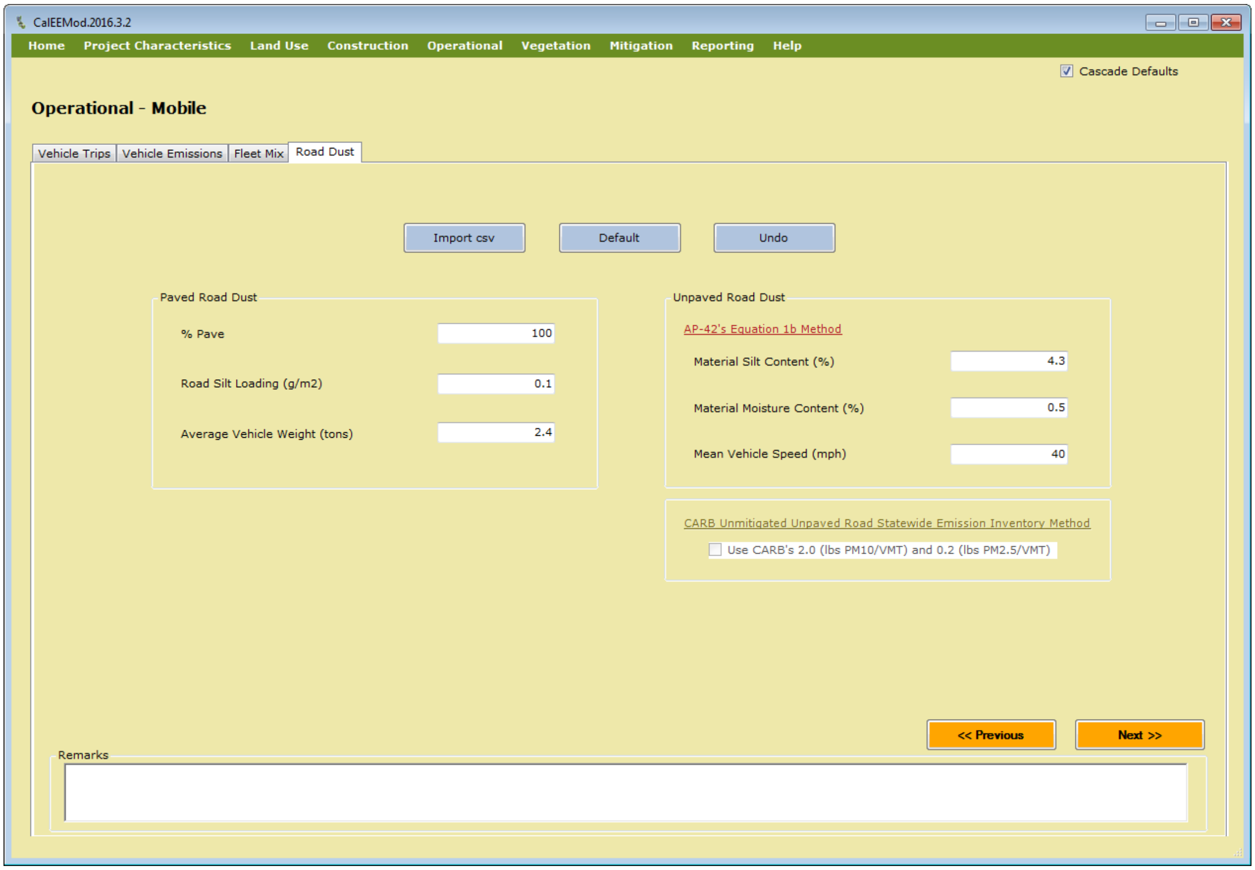
9.3 for Material Silt Content (%) *(instead of 4.3 statewide default)*

0.1 for Material Moisture Content (%) *(instead of 0.5 statewide default)*

32.4 for Mean Vehicle Speed (mph) *(instead of 40 statewide default)*

In CalEEMod Version 2016.3.1, projects located in San Luis Obispo County APCD and Sacramento Metropolitan AQMD were provided an additional option for the user to select CARB's 2.0 lbs. PM_{10}/VMT[9] as the default unmitigated fugitive dust emission factor for unpaved roads during the operational phase. If this default is selected, an emission factor of 0.2 lbs. $PM_{2.5}$/VMT is also applied based on a 10% $PM_{2.5}$/ PM_{10} ratio[10, 11]. By checking the box, the program will use CARB's emission factor to override the calculated emission factor based on USEPA AP-42. Note: For project locations other than San Luis Obispo County APCD and Sacramento Metropolitan AQMD, CARB's 2.0 lbs. PM_{10}/VMT is not an option that the user can select.

9 Available at: http://www.arb.ca.gov/ei/areasrc/fullpdf/full7-10.pdf
10 Available at: http://www3.epa.gov/ttnchie1/ap42/ch13/related/mri_final_fine_fraction_dust_report.pdf
11 Available at: http://www.arb.ca.gov/app/emsinv/emssumcat_query.php?F_YR=2015&F_DIV=-4&F_SEASON=A&SP=2009&F_AREA=CA#0

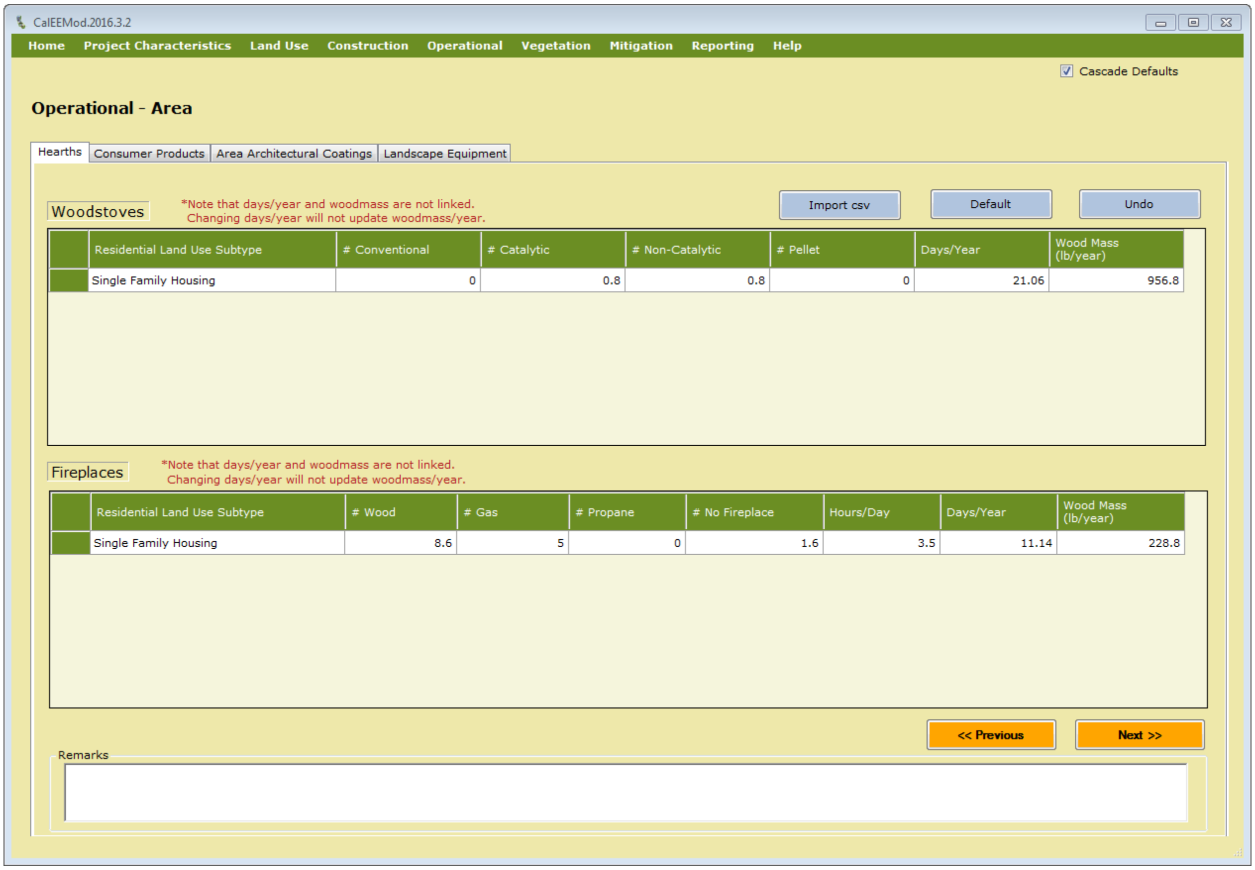


4.5 Area

The area source screen consists of four sub-screens: Hearths, Consumer Products, Area Architectural Coatings, and Landscaping Equipment. Natural gas emission variables from all uses except hearths are included in the energy use screen (described in Section 4.6).

4.5.1 Hearths and Woodstoves

This sub-screen allows the user to enter the number of woodstoves and hearths of various types as well as the usage of these devices. Woodstoves are separate from fireplaces since a home may have both and these devices may have different use patterns. The number of devices that is entered for each device type represents the total number of devices installed in the dwelling units for a particular land use. Appendix A contains the emissions calculation methodology and details of variables that the user cannot override. Some of these emissions may be classified as biogenic and are therefore reported as CO_2-Biogenic. For most locations a default percent of hearths and stoves was provided by air districts and is multiplied through. The number of devices was chosen to include in CalEEMod instead of a percentage to allow for incorporation of various air district rules regarding hearths and woodstoves in new residences without having specialized data entry screens. Commercial land uses by default do not have hearths or woodstoves in CalEEMod. These are included for those cases where they may occur such as in restaurants or hotels.



The San Joaquin Valley jurisdiction has a regulatory limit on the number of hearths depending upon the type and number of residential development. The regulatory limit is generated by CalEEMod but all the input parameters (e.g., unit density, etc.) are necessary to determine the value. Thus, the regulatory limit is disclosed during the reporting stage under the Default Value box in the report. The model, however, calculates emission impacts from the number of hearths inputted on the Area source screen (listed under the New Value column in the report). Therefore, if the user wants to calculate emissions from regulatory limit, the report needs to be run to determine the regulatory limit and the user needs to go back to the Area Source screen to input that value and re-run the report. If the user chooses to calculate emissions from a different number of hearths (e.g., a number of hearths less than the regulatory limit), then that number needs to be inputted on the Area Source screen to properly calculate emissions. Again, the report will provide the regulatory limit under the Default Value column and the user input value under New Value column.

4.5.2 Consumer Products

Consumer products are various solvents used in non-industrial applications which emit ROGs during their product use. These typically include cleaning supplies, kitchen aerosols, cosmetics and toiletries. SCAQMD has developed an emission factor based on the total of all building square footage for both residential and non-residential buildings. Details of how this emission factor was developed can be found in Appendix E. The user can change this emission factor if more relevant data is available. In CalEEMod Version 2016.3.1, ROG emissions from pesticides/fertilizers for City Parks and Golf Courses and ROG emissions from parking surface degreasers were separated from the general consumer products category. Also in CalEEMod Version 2016.3.1, the model also assumes that there would be no ROG emissions from the actual pool surface area for Recreational Swimming Pools because the chemicals used for maintaining pools are not considered to be ROGs. Details of how the ROG emission factors for pesticides/fertilizers and parking surface degreasers were determined can be found in Appendix E.

4.5.3 Area Architectural Coatings

This sub-screen has text boxes for the reapplication rate and coating ROG content for each building surface type and parking surface. The reapplication rate is the percentage of the total surface area that is repainted each year. A default of 10% is used, meaning that 10% of the surface area is repainted each year (i.e., all surface areas are repainted once every 10 years). Daily emissions divide the annual rate by 365 days per year. This is based on assumptions used by SCAQMD in their district rules regarding architectural coatings. Some districts provided details on their coating regulations that phase-in over time, which have been incorporated to the extent feasible, given the general classifications of paint (interior or exterior for residential and non-residential). Coating ROG content from state regulations are used for air districts that did not provide specific architectural coating information. Consult your local air district for suggested values that may be lower than the state regulations.

The ROG contents under the Operational Area Architectural Coatings screen (either CalEEMod defaults or site-specific values defined by users) become the default ROG contents for the Area Mitigation screen. The user may check the box under the Area Mitigation screen and specify a lower ROG content limit.

4.5.4 Landscape Equipment

This sub-screen has two text boxes to show the number of snow days or summer days. In addition, the defaults consider a realistic number of days which the landscaping equipment would be operated. For example, landscaping at commercial facilities typically do not take place during a weekend or during the summer at educational facilities that are not open. The number of days are applied to the appropriate landscape equipment types available in OFFROAD2011 using the average horsepower and load factors of the population mode. The derivation of emission factors used for each equipment type from OFFROAD2011 is described in Appendix A.

4.6 Energy Use

The energy use screen is used to gather the information necessary to estimate the emissions associated with building electricity and natural gas usage (non-hearth). The electricity energy use is in units of kilowatt hours (kWh) per size metric for each land use subtype. Natural gas use is in units of a thousand British Thermal Units (kBTU) per size metric for each land use subtype.

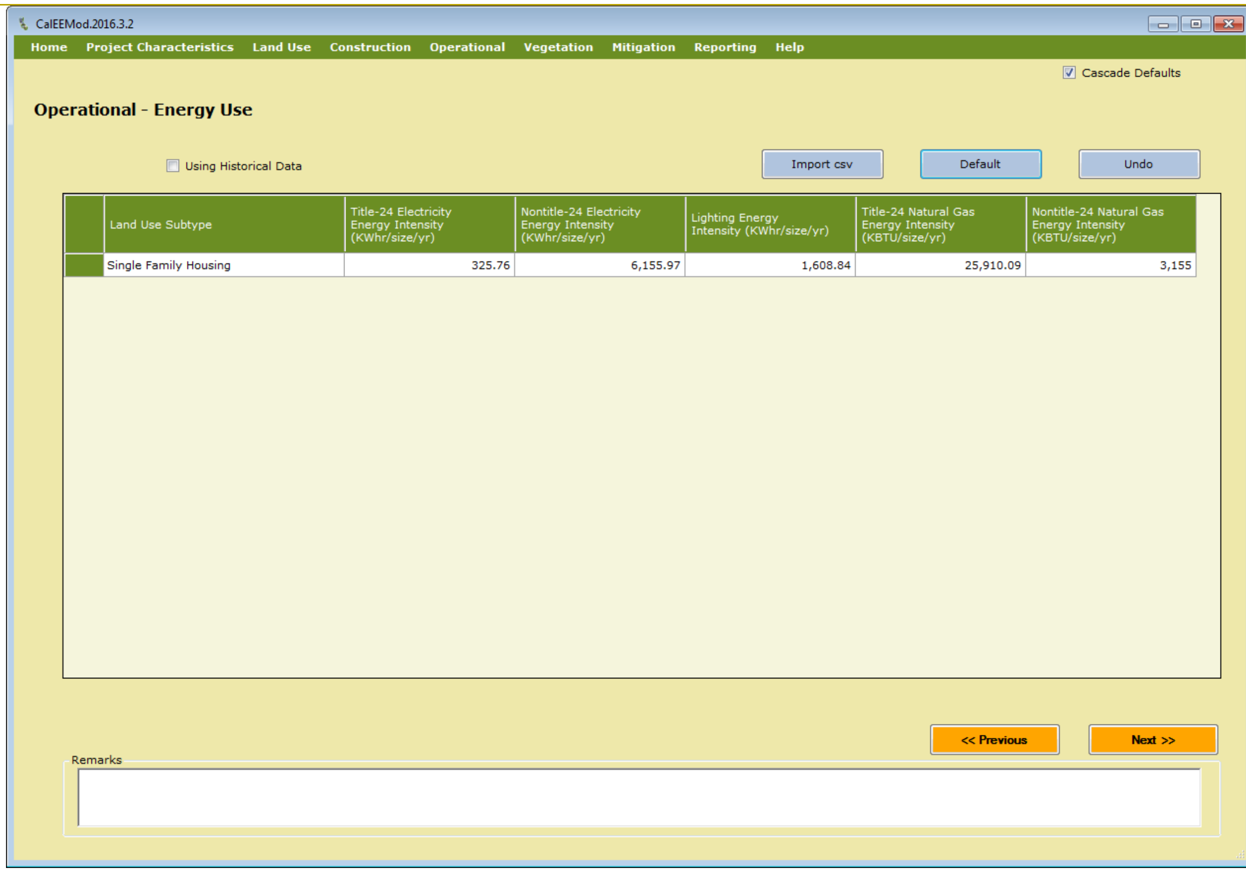
Title 24 of the California Code of Regulations, known as the California Building Standards Code or Title 24, contains energy conservation standards applicable to all residential and non-residential buildings throughout California. With CalEEMod, building electricity and natural gas use is divided into two categories: 1) end uses subject to Title 24 standards; and, 2) end uses not subject to Title 24 standards. The distinction is used when the mitigation measure for exceeding Title 24 standards (BE-1) is applied. Lighting is also a separate category in CalEEMod for which a separate mitigation measures (LUT-1) may be applied for using energy efficient lighting.

For electricity, Title 24 uses include the major building envelope systems covered by Part 6 (California Energy Code) of Title 24 such as space heating, space cooling, water heating, and ventilation. Non-Title 24 uses include all other end uses, such as appliances, electronics, and other miscellaneous plug-in uses. Because some lighting is not considered as part of the building envelope energy budget, and since a separate mitigation measure is applicable to this end use, CalEEMod makes lighting a separate category.

For natural gas, uses are likewise categorized as Title 24 or Non-Title 24, with Title 24 uses including building heating and hot water end uses. Non-Title 24 natural gas uses include cooking and appliances (including pool/spa heaters).

The baseline values are based on the CEC sponsored California Commercial End Use Survey (CEUS) and Residential Appliance Saturation Survey (RASS) studies[12]. For climate zones not included in these surveys, data from the closest climate zone was used as a surrogate. Since these studies are based on older buildings, adjustments have been made to account for changes due to Title 24 building codes as described in Appendix E. The user should select the use historical box if they only want an adjustment to the 2005 standards which were in effect when CARB developed its Scoping Plan 2020 No Action Taken predictions. After selecting the historical button, the user must also click the default button to load the historical default values.

[12] CEC. October 2010. Residential Appliance Saturation Survey. Available at: http://www.energy.ca.gov/appliances/rass
CEC. March 2006. Commercial End-Use Survey. Available at: http://www.energy.ca.gov/ceus/



4.7 Water and Wastewater Use

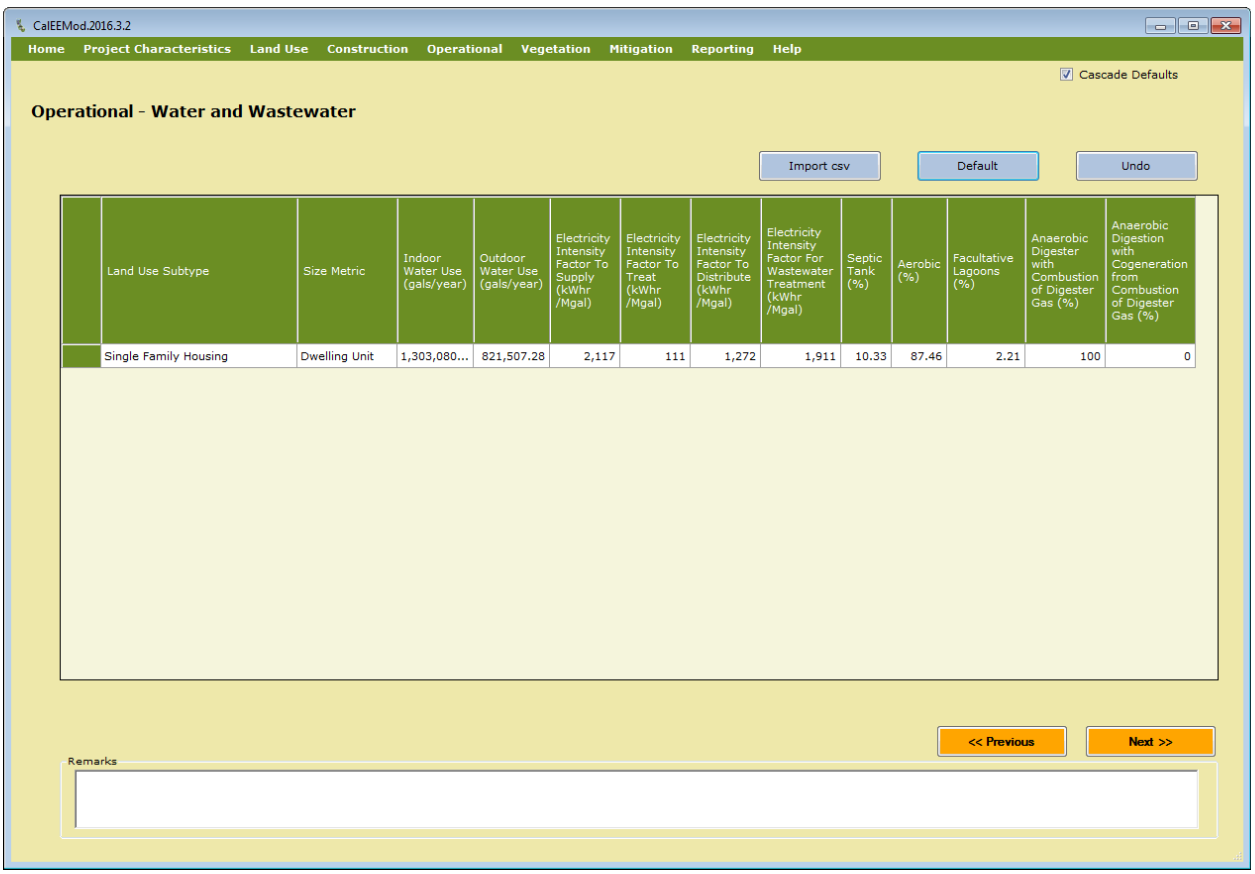
This screen estimates the land uses contribution of GHG emissions associated with supplying and treating water and wastewater. This screen is used to enter the amount of water in gallons used indoors and outdoors for each land use subtype[13]. The indoor water is also used to estimate the amount of wastewater. The electricity intensity factor for various phases of providing water is provided. Depending on the specific water supply used or treatment method used these numbers can vary over a wide range. Supplying water is bringing the water from its primary source such as the ground, river, or snowpack to the treatment plant. Distributing the water is bringing the water from the treatment plant to the end users. The electricity intensity

[13] Gleick, P.H.; Haasz, D.; Henges-Jeck, C.; Srinivasan, V.; Cushing, K.K.; Mann, A. 2003. Waste Not, Want Not: The Potential for Urban Water Conservation in California. Published by the Pacific Institute for Studies in Development, Environment, and Security. Full report available at: http://www.pacinst.org/reports/urban_usage/waste_not_want_not_full_report.pdf.
Appendices available at: http://pacinst.org/publication/waste-not-want-not/

Dziegielewski; B.; Kiefer, J.C.; Optiz, E.M.; Porter, G.A.; Lantz, G.L.; DeOreo, W.B.; Mayer, P.W.; Nelson, J.O. 2000. Commercial and Institutional End Uses of Water. Published by the American Water Works Association Research Foundation.

Northern California Golf Association. Improving California Golf Course Water Efficiency. Available at: http://www.water.ca.gov/wateruseefficiency/docs/2004Apps/2004-079.pdf factors are multiplied by the utility GHG emissions intensity factors for the GHGs and are classified as indirect emissions. The default electricity intensity is from the CEC's 2006 Refining Estimates of Water-Related Energy Use in California using the average values for Northern and Southern California[14]. The location will automatically select the appropriate values if using these defaults. Since the electricity can vary greatly based on locations, the user should override these values if they have more specific information regarding their specific water supply and treatment.

Wastewater may also have direct emissions of GHGs. These depend on the type of wastewater treatment system (e.g., septic, aerobic or lagoons) used and therefore the wastewater treatment type percentages are variables. In addition, the model calculates impacts if the solids are digested either through an anaerobic digester or with co-generation from combustion of digester gas. Each type has associated GHG emission factors. Some of these may be classified as biogenic. Not all of the biogenic emissions are accounted for since there are not adequate emissions factors at this time. Refer to Appendix A on how to properly change the defaults, if necessary, and the methodology used to calculate impacts from wastewater treatment.



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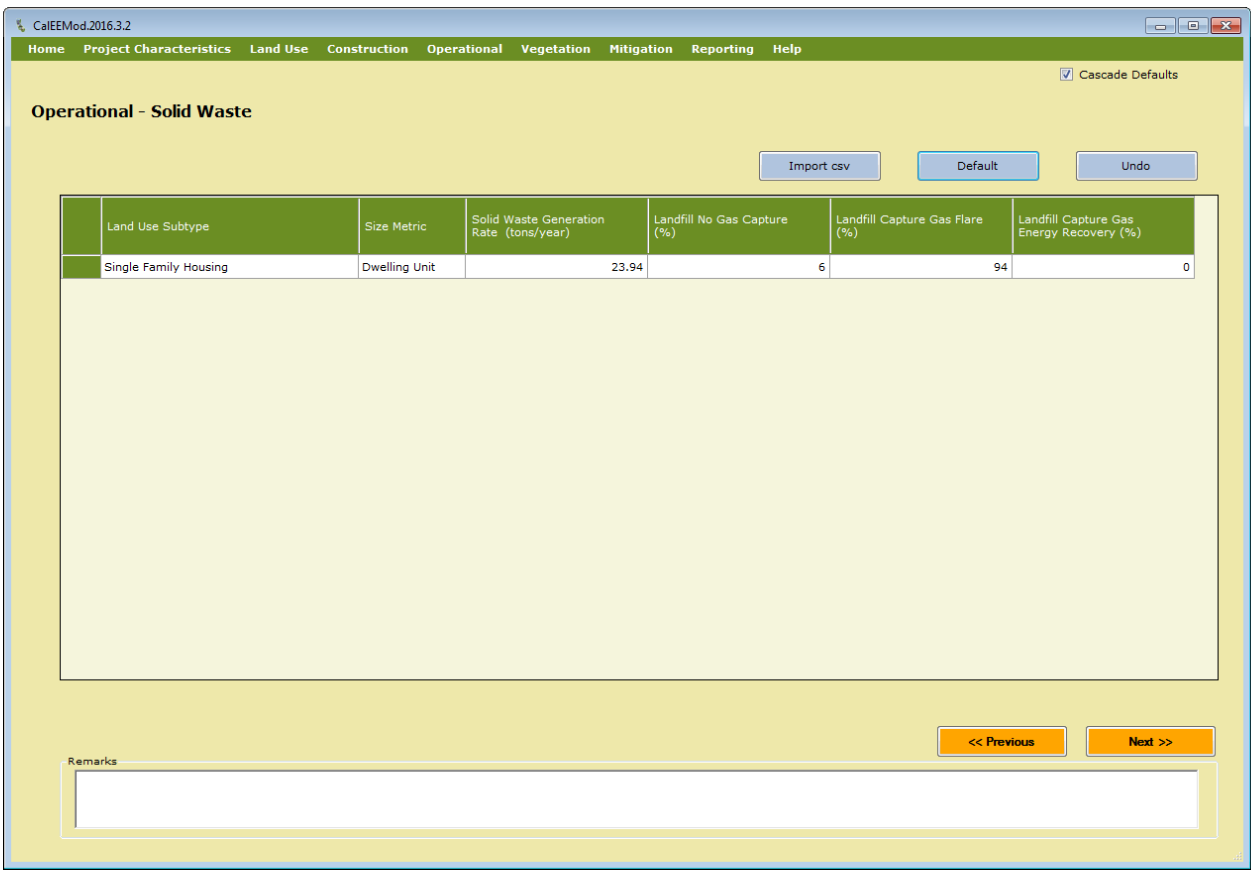
[14] CEC-500-2006-118. Available at http://www.energy.ca.gov/2006publications/CEC-500-2006-118/CEC-500-2006-118.PDF.

4.8 Solid Waste

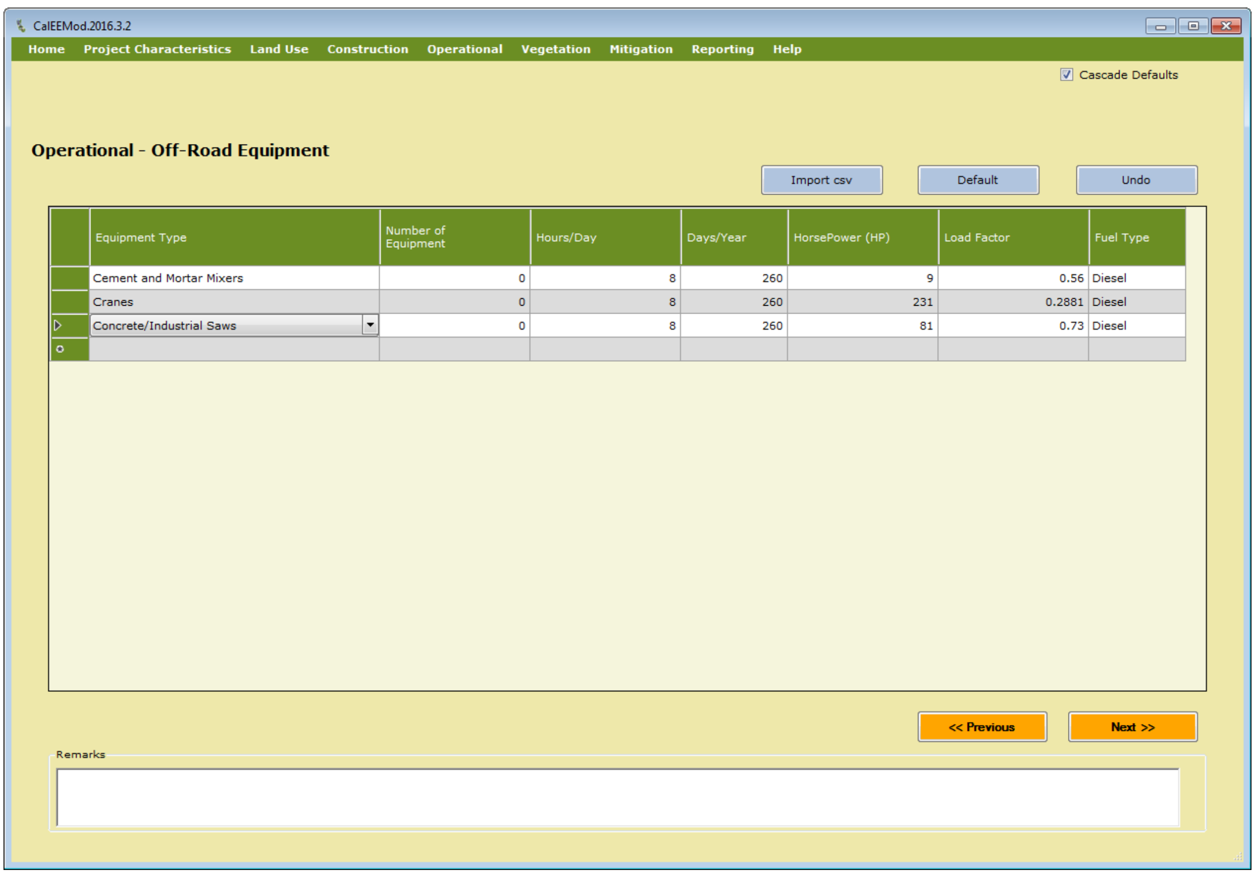
The solid waste screen determines the GHG emissions associated with disposal of solid waste into landfills. In order to estimate the eventual contribution of GHG emissions from solid waste disposed by a land use annually, the total amount of carbon dioxide and methane that would be evolved over the span of many years is calculated. This is based on the IPCC's methods for quantifying GHG emissions from solid waste using the degradable organic content of waste[15]. Waste disposal rates by land use and overall composition of municipal solid waste in California is primarily based on CalRecycle data. The amount of methane emitted depends on characteristics of the landfill, and therefore the default percentage is based on the types of landfills assumed by CARB in their GHG emissions inventories. Portions of these emissions are biogenic. The defaults for the gas capture (e.g., no capture, flaring, energy recovery) are statewide averages except for Santa Barbara APCD which has a 100% landfill capture gas flare. The user has the ability to override the defaults if the gas capture at the landfill to be used by the project is known. Local jurisdictions can also provide guidance to users as to what default properly reflects known regional solid waste gas capture.



15 IPCC. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 5 Waste. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html.

4.9 Off-Road Equipment

The Operational - Off-Road Equipment sub-screen allows the user to identify any off-road equipment used during operational activities (e.g., forklifts, cranes, loaders, generator sets, pumps, pressure washers, etc.) at the project site. Because such equipment cannot be assumed to be needed for a particular land use project, a user must provide the data in order for CalEEMod to calculate the resulting emissions from off-road equipment operation. A dropdown list of off-road equipment is provided for the user to identify each piece of equipment. The model requires the following specific information per equipment type. The user would need to provide the number of pieces for each equipment type. The model assumes an operation activity of 8 hours per day and 260 days per year, as well as the horsepower and load factor of the equipment type, but the user has the ability to override the default assumptions with project specific information. Finally, the model assumes diesel fuel, but a dropdown menu is provided to allow the user to choose bio-diesel, compressed natural gas (CNG) or electrical if known, to power the equipment.

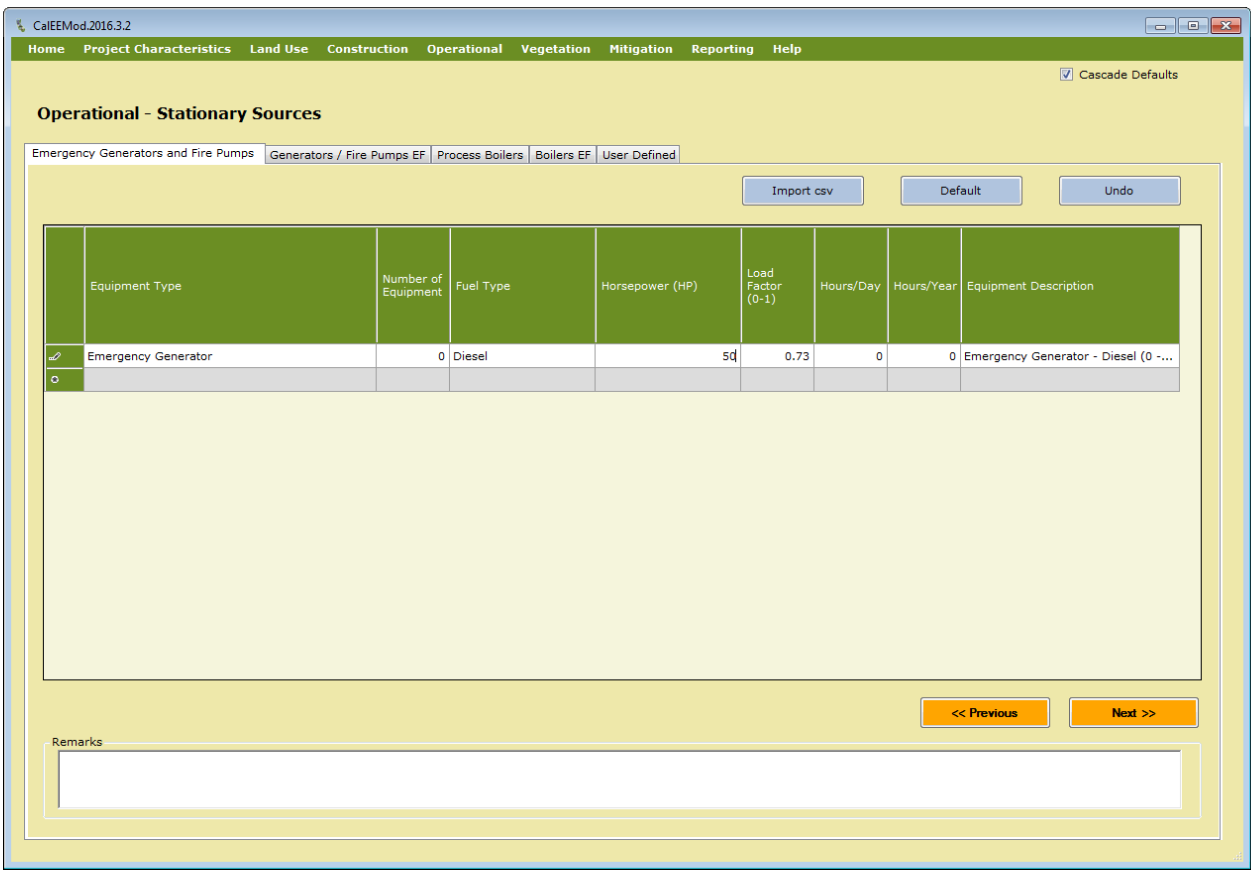


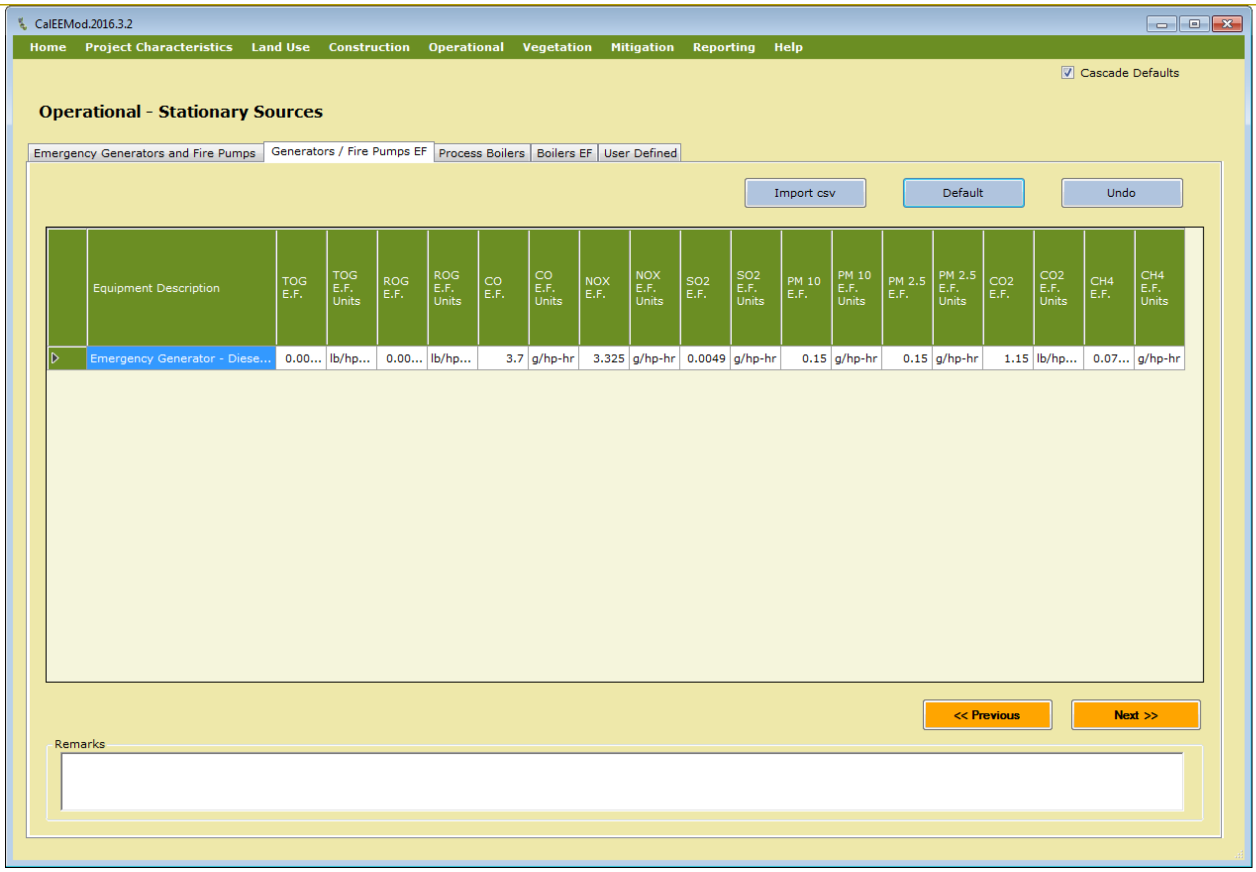
4.10 Stationary Sources

The Stationary Sources screen consists of five sub-screens: Emergency Generators and Fire Pumps and their default emission factors, Process Boilers and their default emission factors, and User Defined Sources. Consult with the local air district to determine if permitted stationary sources should be included in the project analysis using CalEEMod.

4.10.1 Emergency Generator and Fire Pumps and Default Emission Factors

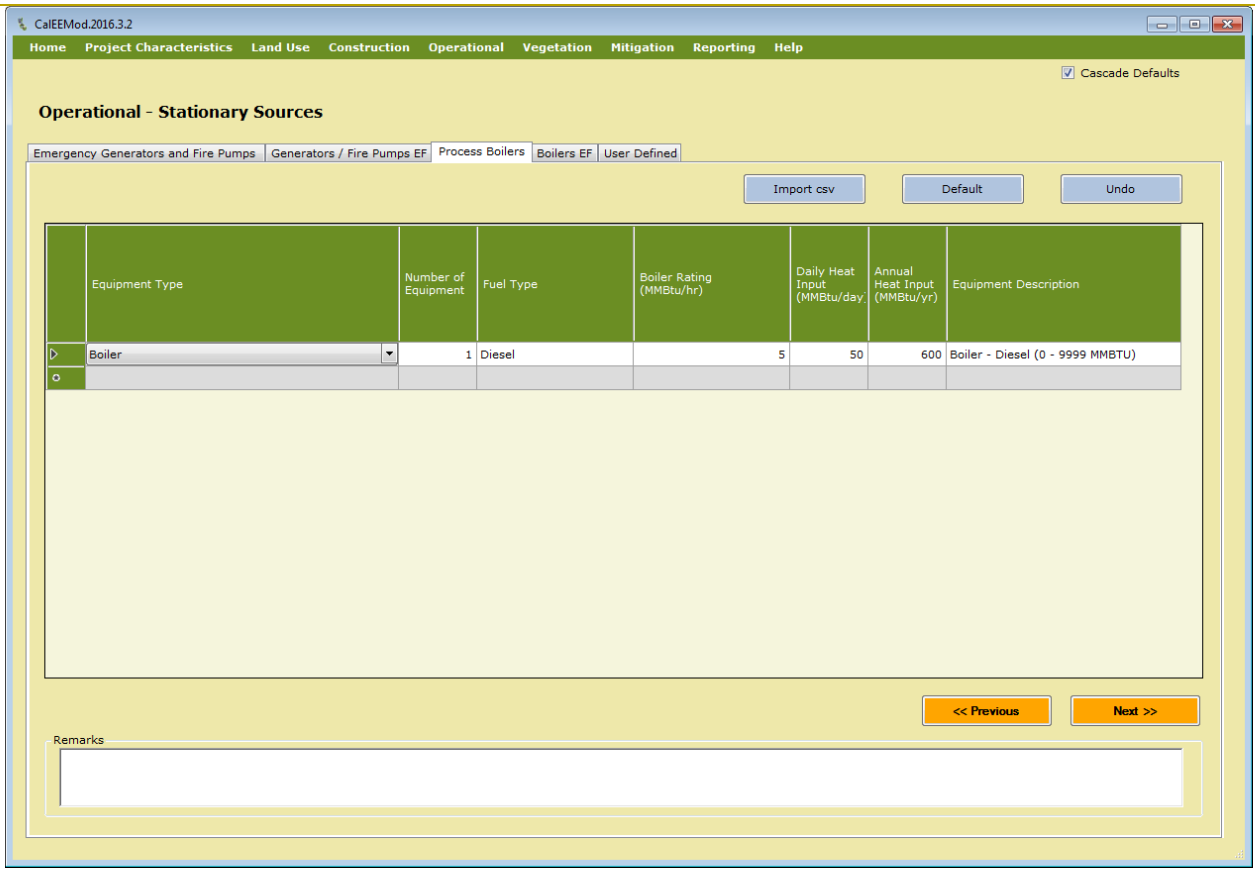
Two sub-screens allow the user to enter emergency power generators and diesel fueled fire pumps and to estimate emissions. This type of equipment operates only for maintenance and testing, or during emergency situations, such as power failures. To calculate emissions, the user must enter the engine rating (in horsepower), the anticipated maximum daily usage, and the anticipated maximum annual usage into the Emergency Generators and Fire Pumps sub-screen. The user may change the default load factor. The default emission factors for the equipment are shown on the separate Generators/Fire Pumps EF (emission factor) sub-screen. The user can replace the default emission factors, but needs to provide custom emission factors in the predefined units. See Appendix A for the sources of default emission factors and emission calculation methodology.

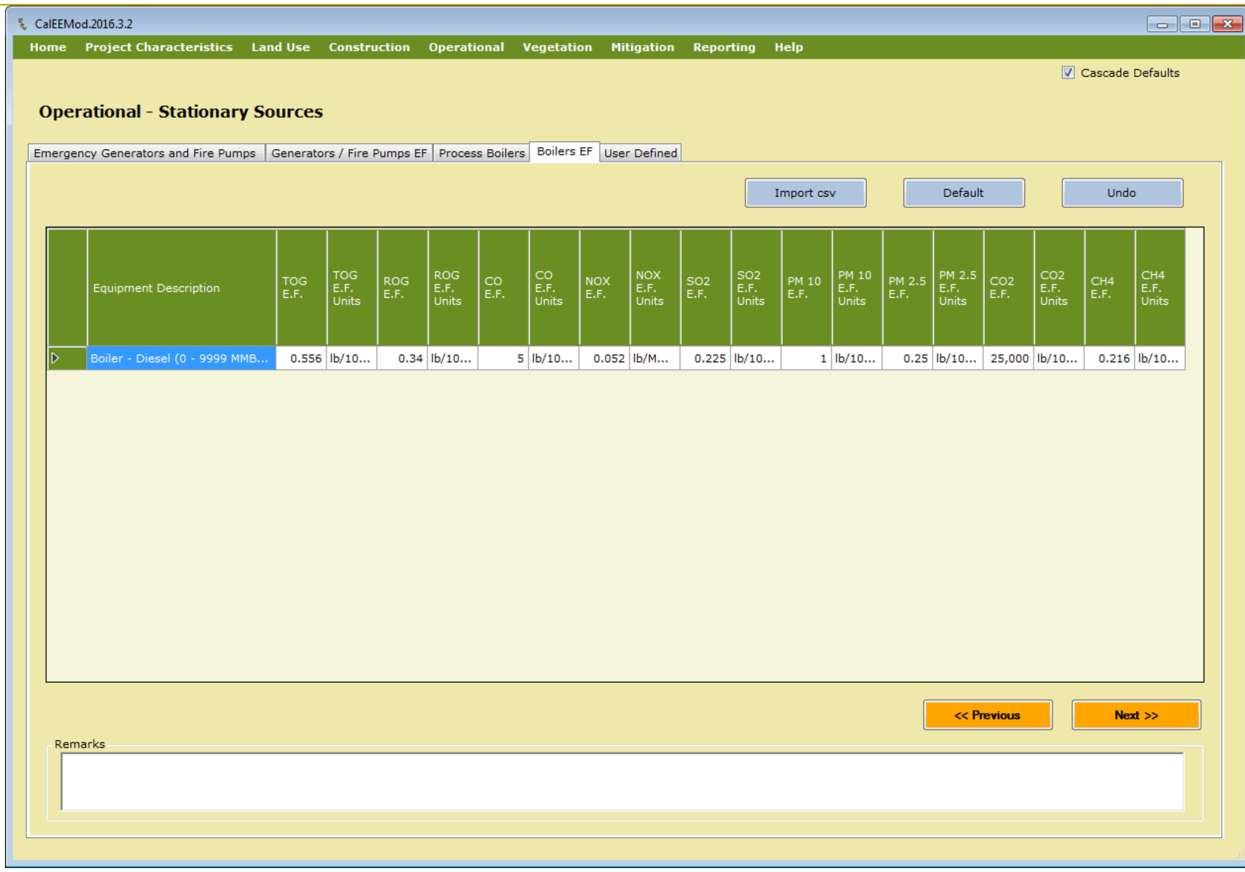




4.10.2 Process Boilers and Default Emission Factors

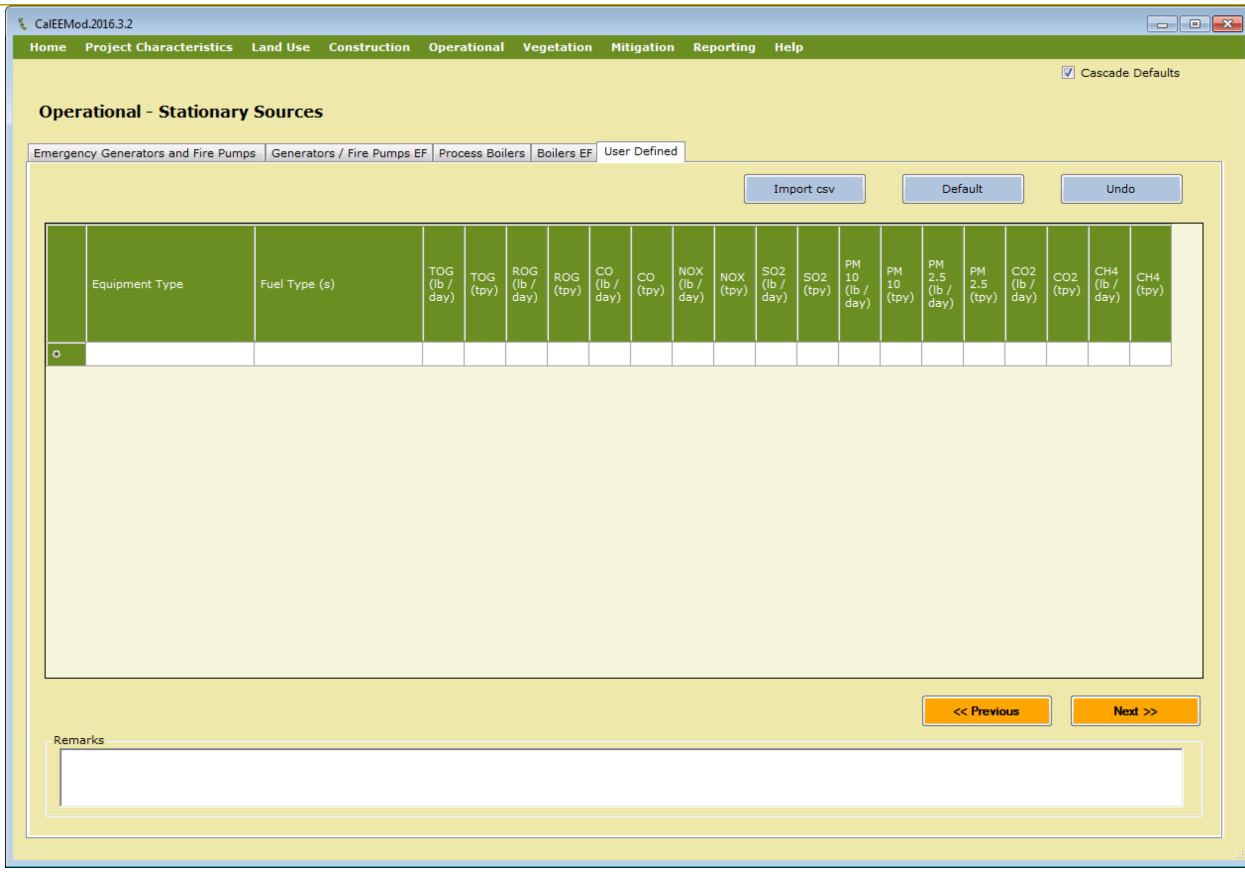
Two sub-screens allow the user to enter process boilers and to estimate emissions. Do not use this option for boilers providing space heating or building hot water, as these uses are included building energy use (See Subchapter 4.6). To calculate process boiler emissions, the user must enter the boiler rating (in million BTU/hr) and maximum anticipated daily and annual heat input in the Process Boilers sub-screen. The default emission factors for boilers are shown on the separate Boiler EF (emission factor) sub-screen. The user can replace the default emission factors, but needs to provide custom emission factors in the predefined units. See Appendix A for the sources of default emission factors and emission calculation methodology.


CalEEMod.2016.3.2
Home
Project Characteristics
Land Use
Construction
Operational
Vegetation
Mitigation
Reporting
Help
Cascade Defaults
Operational - Stationary Sources
Emergency Generators and Fire Pumps
Generators / Fire Pumps EF
Process Boilers
Boilers EF
User Defined
Import csv
Default
Undo
Equipment Type
Number of Equipment
Fuel Type
Boiler Rating (MMBtu/hr)
Daily Heat Input (MMBtu/day)
Annual Heat Input (MMBtu/yr)
Equipment Description
Boiler
1
Diesel
5
50
600
Boiler - Diesel (0 - 9999 MMBTU)
<< Previous
Next >>
Remarks



4.10.3 User Defined

An option for the user to define stationary sources other than emergency generators, fire pumps and process boiler has been included in the User Defined sub-screen. Emissions for this source would include any other miscellaneous sources that typically require permits to operate issued by an air district. Emissions may be manually entered here, either by transferring values from the permits to operate, or by calculating emissions outside of CalEEMod. Any emissions entered here will be transferred to the appropriate reports.



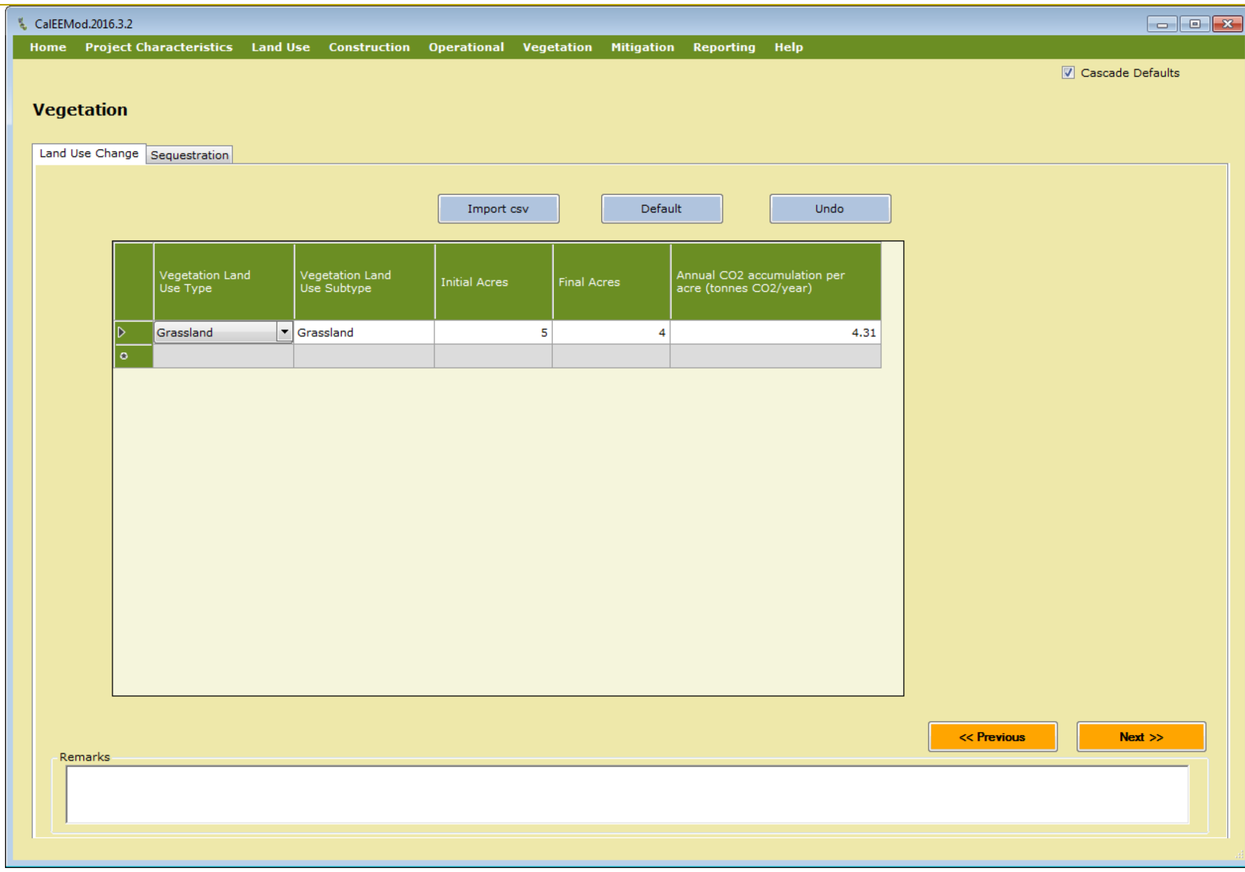
4.11 Vegetation

The vegetation screen is used to estimate the one-time change in carbon sequestration capacity due to a project. There are two sub-screens, Land Use Change and Sequestration. The methods used are based on IPCC[16].

4.11.1 Land Use Change

The Land Use Change sub-screen estimates GHG emissions due to a change in vegetation resulting from a change in land use type. The user enters the vegetation land use type, the initial and final acreage of the vegetation land use type, and the annual carbon dioxide equivalent accumulation per acre if the user chooses to override the default value. Settlement land use acreage is not considered since it is a net zero at steady state unless trees are added.

[16] IPCC. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 4. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html



4.11.2 Sequestration

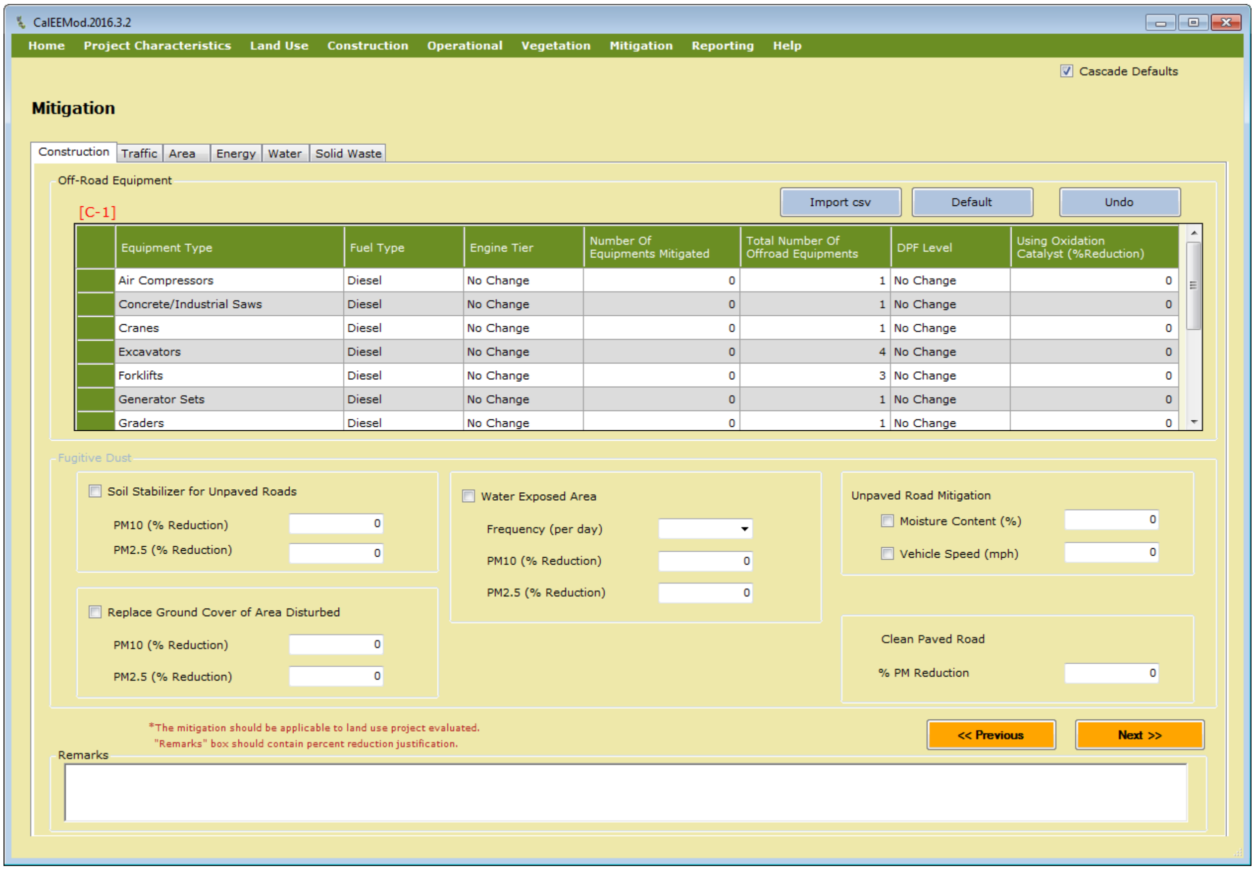
This sub-screen of Vegetation is used to estimate the GHG emissions associated with the sequestration of net new trees added to the project site. Consistent with IPCC recommendations a 20 year active growth period is assumed. The user enters the tree type or miscellaneous if it is not known, and the total number of trees. The user can override the default carbon sequestration rate.

4.12 Mitigation

The mitigation screen consists of six sub-screens that the user can indicate and supply the necessary information to estimate the emissions after mitigation measures have been implemented. The mitigation measures included in CalEEMod are largely based on the CAPCOA Quantifying Greenhouse Gas Mitigation Measures (http://www.capcoa.org/wp-content/uploads/downloads/2010/09/CAPCOA-Quantification-Report-9-14-Final.pdf) document. The CAPCOA measure numbers are provided next to the mitigation measures in CalEEMod to assist the user in understanding each measure by referencing back to the CAPCOA document. This User's Guide focuses on key aspects of the Mitigation sub-screens that users should pay particular attention.

4.12.1 Construction Mitigation

This sub-screen consists of a datagrid of off-road construction equipment to apply various mitigation measures and check boxes with supplemental information for fugitive dust emissions mitigation.



To apply mitigation to construction equipment, the user selects the equipment type, notes the number of equipment mitigated (of the total number of off-road equipment listed), and type of mitigation that applies. If substantial evidence supporting reductions was available at the time of development, options include fuel type (diesel, CNG, electric, hybrid, biodiesel), engine tier (typically select Tier 4), diesel particulate filter tiers (Tier 3 being the most effective), and use of oxidative catalysts. The program estimates how much if any increase or decrease in emissions to apply for each pollutant. Some mitigation measures have trade-offs in pollutant reductions and therefore may result in increases of some pollutants. The mitigation option to use alternative fuel for construction equipment is consistent with mitigation measure C-1 in the CAPCOA Quantifying GHG Mitigation document.

To apply mitigation to construction fugitive dust, the user selects the check box in front of the mitigation measure name, and enters in the appropriate information in the drop down or text boxes. Some fugitive dust mitigation required by some air districts do not appear here since the fugitive dust source they mitigate is not quantified by CalEEMod, in particular this includes fugitive dust generated by wind over land and storage piles. Since the fugitive dust source is not quantified it is not appropriate to apply the reduction.

For Unpaved Road Mitigation for construction fugitive dust, the maximum vehicle speed and the minimum moisture content for unpaved roads are entered. Defaults for these values are those entered on the On-Road Fugitive Dust screen. Mitigated emissions are calculated using the VMT from on-road vehicles traveling along unpaved roads, previously calculated from the percentages entered on the On-road Fugitive Dust Screen (e.g., % Pave Worker, % Pave Vendor or % Pave Hauling).

Users may check the boxes and provide a lower vehicle speed and a higher moisture content to conduct the mitigation calculation. If during a particular construction phase the user defined mitigated vehicle speed is higher than the unmitigated vehicle speed and/or the user defined mitigated moisture content is lower than the unmitigated moisture content, a warming message will be displayed. In this case, the unmitigated values will be used, resulting in no mitigation being calculated.

4.12.2 Traffic Mitigation

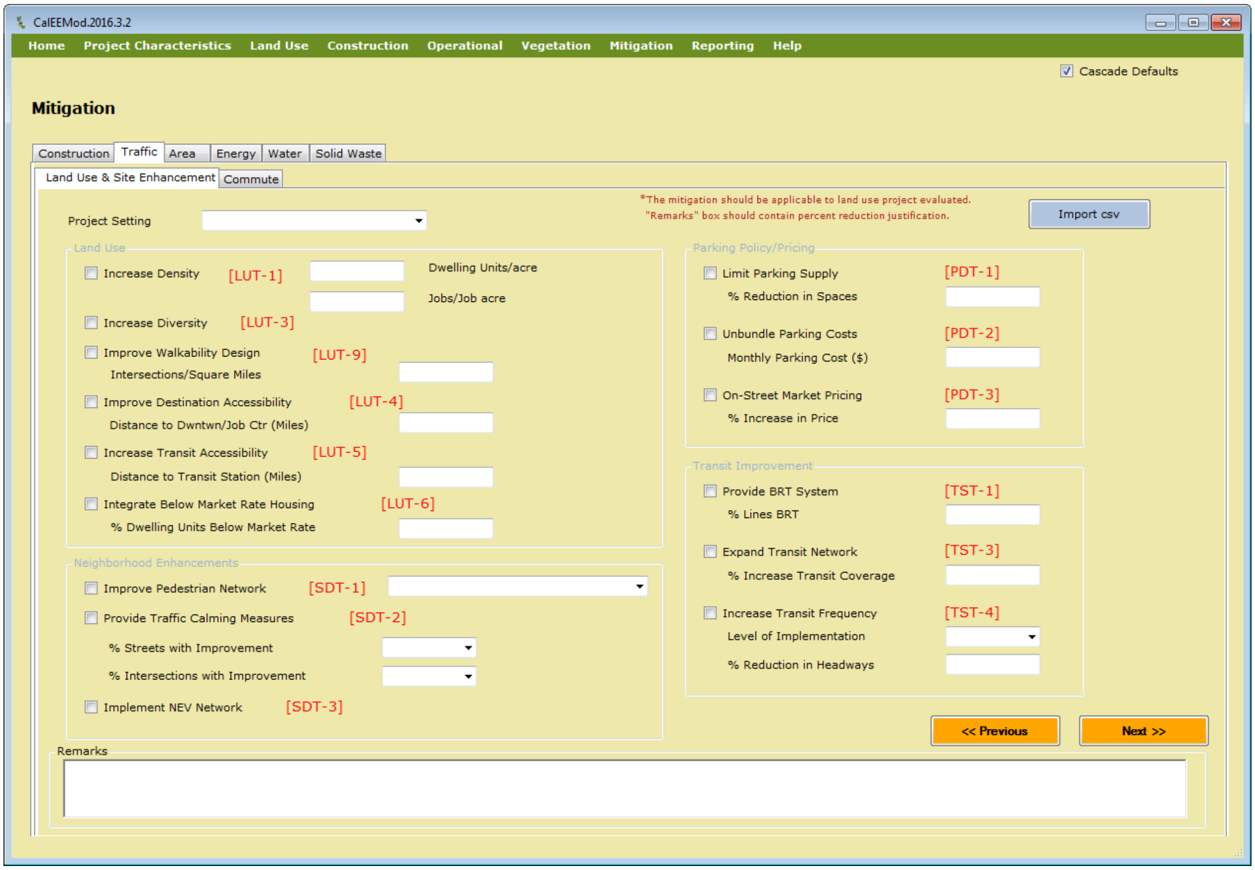
There are two traffic mitigation sub-screens that the user can select from, Land Use & Site Enhancement and Commute. First, the user must select the Project Setting as defined in the CAPCOA document (pp. 59-60).

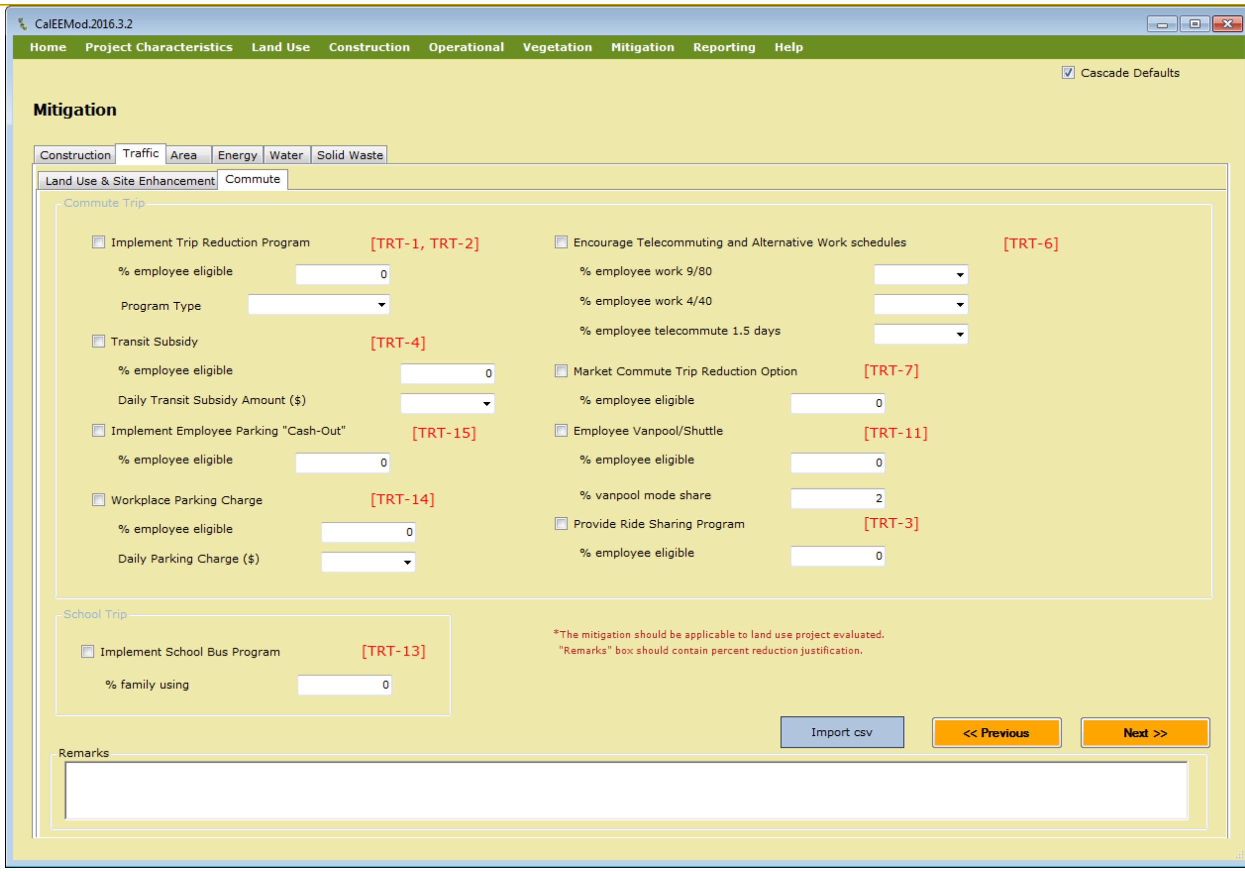
- Low Density Suburban: An area characterized by dispersed, low-density, single-use, automobile dependent land use patterns, usually outside of the central city (a suburb).
- Suburban Center: An area that serves the population of the suburb with office, retail and housing which is denser than the surrounding suburb.
- Urban: An area which is located within the central city with higher density of land uses than you would find in the suburbs. It may be characterized by multi-family housing and located near office and retail.
- Urban Center *(referred to as Compact Infill in the CAPCOA document)*: An area which is located within or contiguous with the central city. Examples may include redevelopment areas, abandoned sites, or underutilized older buildings/sites.

If the CAPCOA measure did not distinguish between Suburban Center and Low Density Suburban, values for Low Density Suburban were used. Similarly, if Urban Center and Urban values were not distinguished, Urban values were used.

The user checks the box next to each mitigation measure and fills in the appropriate information as required. The maximum reduction caps defined in the CAPCOA Quantifying GHG Mitigation document are integrated into these calculations. The CAPCOA traffic mitigation measure numbers included in CalEEMod are the following: LUT-1, LUT-3, LUT-9, LUT-4, LUT-5, LUT-6, SDT-1, SDT-2, SDT-3, PDT-1, PDT-2, PDT-3, TST-1, TST-3, TST-4, TRT-1, TRT-2, TRT-4,

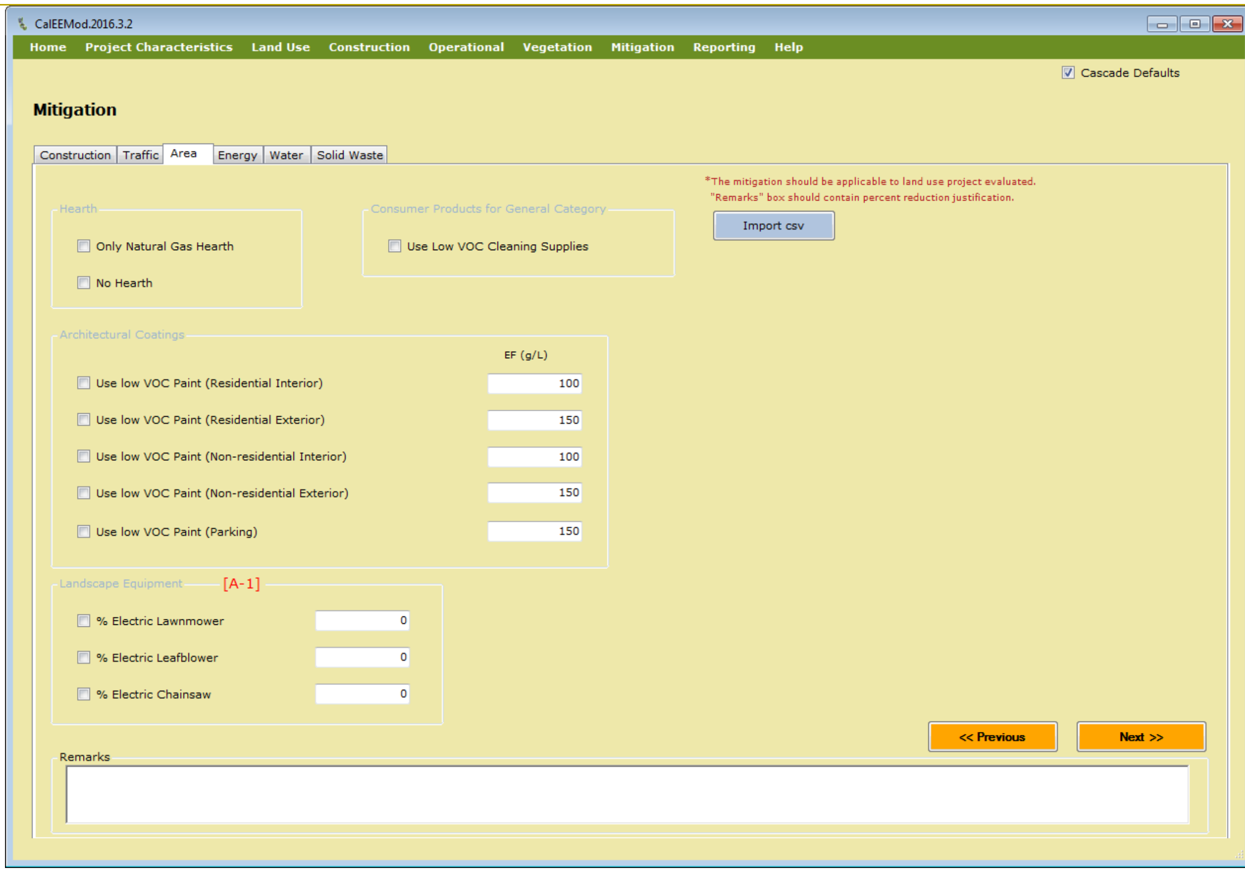
TRT-15, TRT-14, TRT-6, TRT-7, TRT-11,TRT-3, and TRT-13. The NEV network mitigation measure (SDT-3) assumes the low end of the CAPCOA recommendations.





4.12.3 Area Mitigation

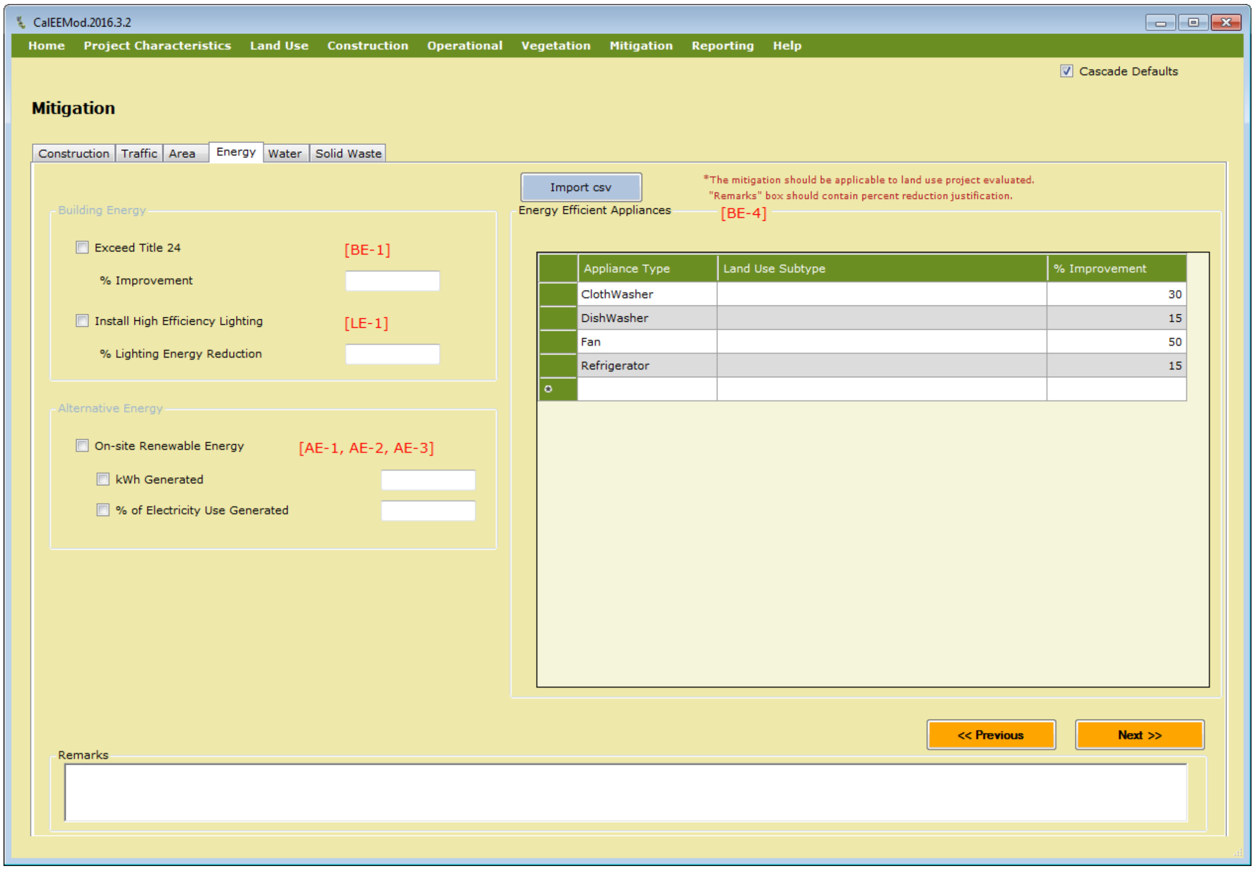
The user can select from a few area source mitigation measures on the Area sub-screen by checking the appropriate box and supplying any additional information in the text boxes. These measures include all natural gas hearths, no hearths, electric landscaping equipment use, reduced ROG coatings, and reduced general category consumer product ROG content. The area landscaping mitigation to prohibit gas powered landscape equipment is consistent with mitigation A-1 in the CAPCOA Quantifying GHG Mitigation document.



4.12.4 Energy Mitigation

The user selects energy mitigation measures on the Energy sub-screen by using the check boxes or the datagrid. These correspond to CAPCOA Mitigation Measures LE-1, BE-1, AE-1, AE-2, AE-3 and BE-4 as listed in the CAPCOA Quantifying GHG Mitigation document. The lighting is a percentage reduction in lighting as supplied by the user. The datagrid is used to enter the land use subtypes that will use energy efficient appliances. The percent improvement is the typical percent improvement above standard appliances according to the 2008 Energy Star Annual Report[17]. Alternative Energy has two methods to enter the amount of alternative energy. The first is the amount of kW-hr generated. The second is the percentage of the total electricity use by buildings that is generated. At this time alternative energy methods that are not carbon neutral are not quantified. To apply the amount of alternative energy only one of the two methods (kW-hr or percentage) needs to be entered for CalEEMod to calculate emission reductions.

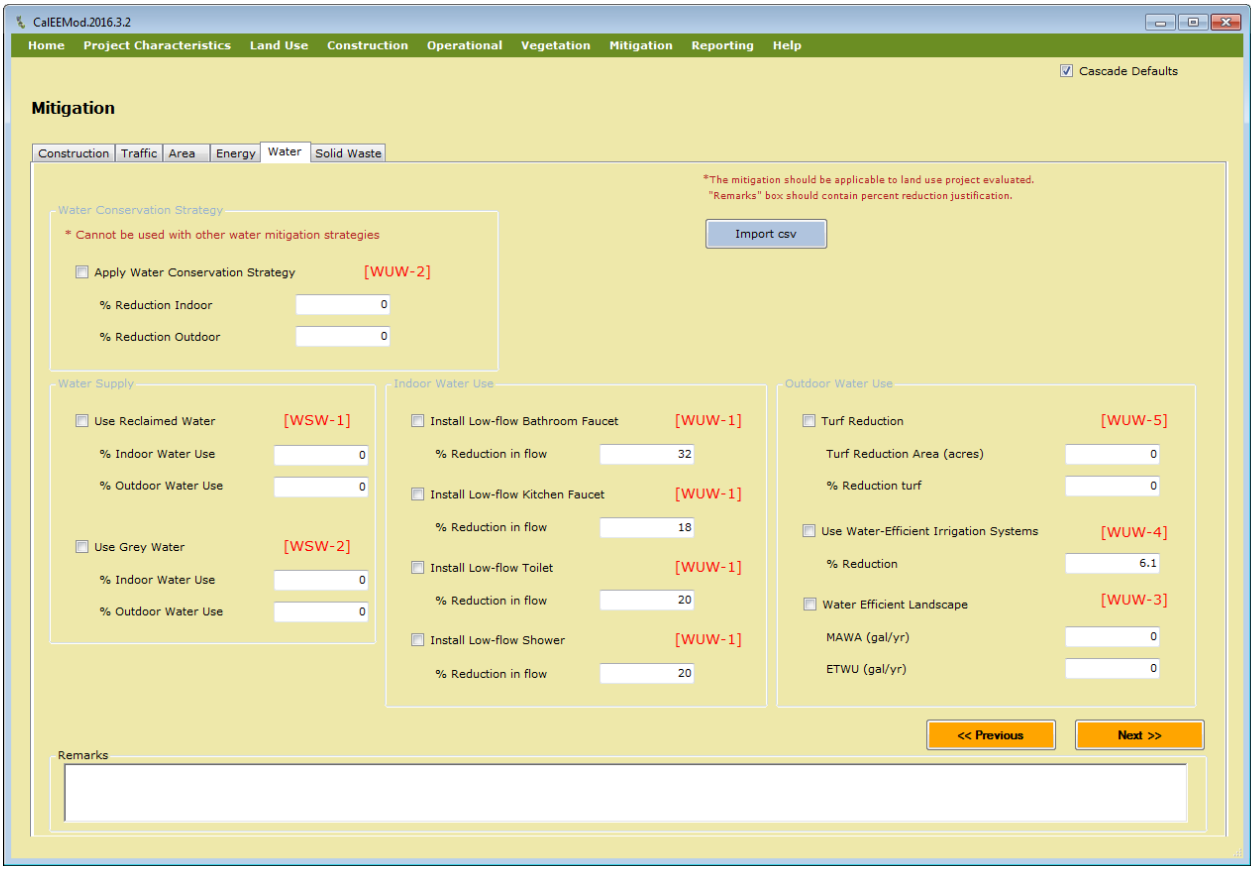
[17] Available at: https://www.energystar.gov/ia/partners/annualreports/annual_report_2008.pdf



4.12.5 Water Mitigation

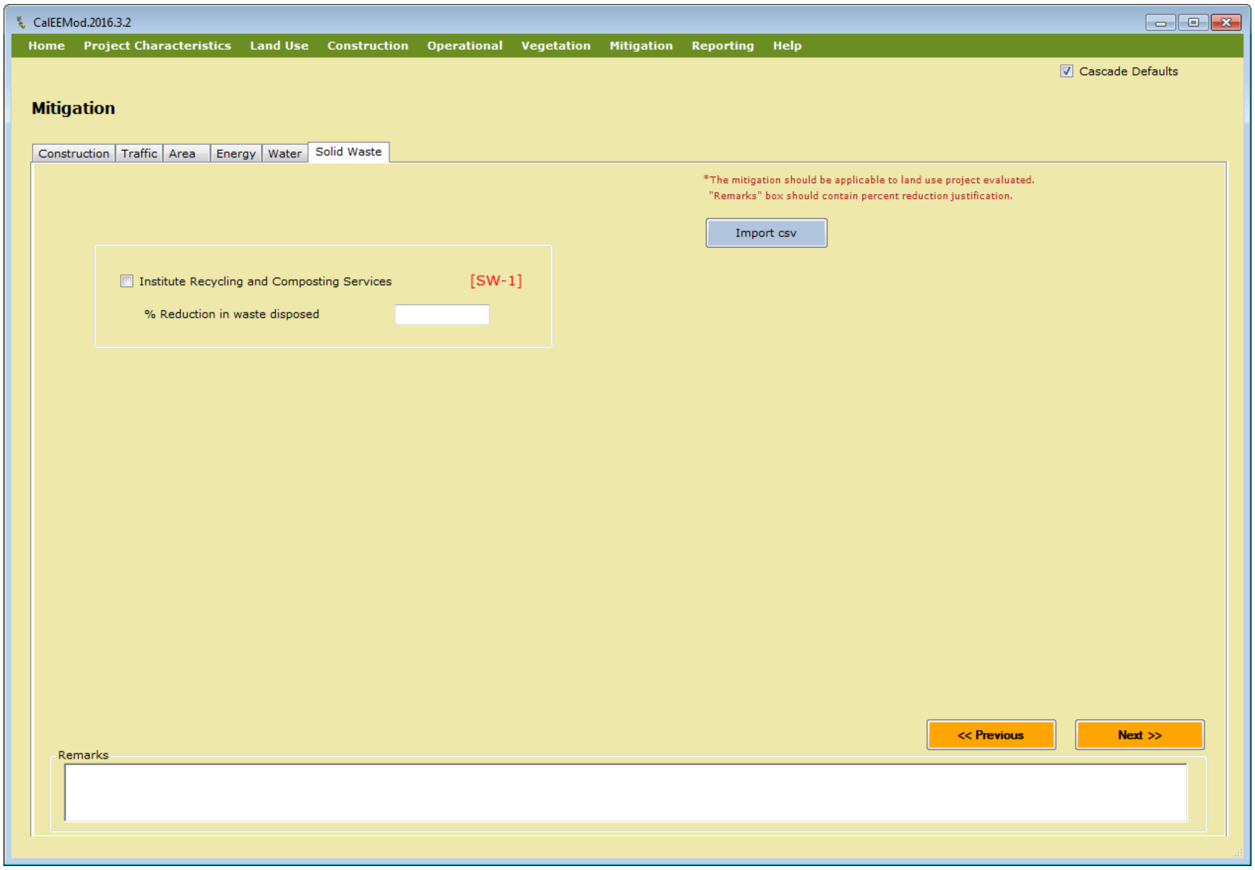
On the Water sub-screen, water mitigation can either be estimated as the percent reduction based on a water conservation strategy or the other individual mitigation measures. The CAPCOA Quantifying GHG Mitigation document includes water supply and use measures WSW-1 & 2, and WUW-1 through 5.

For CAPCOA Mitigation Measure WSW- 3 (Use Locally Sourced Water Supply), using locally-sourced water or water from less energy-intensive sources reduces the electricity and indirect CO_2 emissions associated with water supply and transport because water from local or nearby groundwater basins, nearby surface water and gravity-dominated systems have smaller energy-intensity factors. This mitigation measure is not included in the Water mitigation sub-screen, therefore, to implement WSW-3, the user should alter the energy intensity values in water and run a separate CalEEMod run to accommodate these values.


CalEEMod.2016.3.2
Home
Project Characteristics
Land Use
Construction
Operational
Vegetation
Mitigation
Reporting
Help
Cascade Defaults
Mitigation
Construction
Traffic
Area
Energy
Water
Solid Waste
*The mitigation should be applicable to land use project evaluated.
"Remarks" box should contain percent reduction justification.
Import csv
Water Conservation Strategy
* Cannot be used with other water mitigation strategies
Apply Water Conservation Strategy [WUW-2]
% Reduction Indoor 0
% Reduction Outdoor 0
Water Supply
Use Reclaimed Water [WSW-1]
% Indoor Water Use 0
% Outdoor Water Use 0
Use Grey Water [WSW-2]
% Indoor Water Use 0
% Outdoor Water Use 0
Indoor Water Use
Install Low-flow Bathroom Faucet [WUW-1]
% Reduction in flow 32
Install Low-flow Kitchen Faucet [WUW-1]
% Reduction in flow 18
Install Low-flow Toilet [WUW-1]
% Reduction in flow 20
Install Low-flow Shower [WUW-1]
% Reduction in flow 20
Outdoor Water Use
Turf Reduction [WUW-5]
Turf Reduction Area (acres) 0
% Reduction turf 0
Use Water-Efficient Irrigation Systems [WUW-4]
% Reduction 6.1
Water Efficient Landscape [WUW-3]
MAWA (gal/yr) 0
ETWU (gal/yr) 0
<< Previous
Next >>
Remarks

4.12.6 Solid Waste Mitigation

The user can calculate an emissions reduction for recycling waste. This mitigation measure corresponds to CAPCOA Mitigation Measure: SW-1.



4.13 Reporting

The user initiates final emission calculations by selecting the report and clicking on the Recalculate All Emissions and Run Report button. The available reports include: Annual, Summer (peak) Daily, Winter (peak) Daily, Mitigation and Summary of peak daily emissions and annual GHG emissions. A separate report viewer will appear on the screen. From this report viewer, the user can view the each selected report on-screen, print each report, save each report as either a Microsoft Excel .xls file, an Adobe Acrobat .pdf file, or in the case of the Mitigation report, a Microsoft Word .doc file. It is important to note that the data presented in the Excel file has already been calculated and the calculated results are placed in the grids as text. For this reason, the user cannot change an emission value presented in an Excel file and expect the report to calculate a revised value. These values, however, can be copied to new Excel spreadsheet for any further desired calculation with the data. If the user elects to generate a Summary report, the project needs to use only the CalEEMod defaults and there can be no remarks on any page.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Life Prediction Model for Grid-Connected Li-ion Battery Energy Storage System

Preprint

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SunPower Corp.

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Life Prediction Model for Grid-Connected Li-ion Battery Energy Storage System

Kandler Smith, Aron Saxon, Matthew Keyser, Blake Lundstrom, Ziwei Cao, Albert Roc

Abstract— **Lithium-ion (Li-ion) batteries are being deployed on the electrical grid for a variety of purposes, such as to smooth fluctuations in solar renewable power generation. The lifetime of these batteries will vary depending on their thermal environment and how they are charged and discharged. To optimal utilization of a battery over its lifetime requires characterization of its performance degradation under different storage and cycling conditions. Aging tests were conducted on commercial graphite/nickel-manganese-cobalt (NMC) Li-ion cells. A general lifetime prognostic model framework is applied to model changes in capacity and resistance as the battery degrades. Across 9 aging test conditions from 0°C to 55°C, the model predicts capacity fade with 1.4% RMS error and resistance growth with 15% RMS error. The model, recast in state variable form with 8 states representing separate fade mechanisms, is used to extrapolate lifetime for example applications of the energy storage system integrated with renewable photovoltaic (PV) power generation. Uncertainty quantification and further validation are needed.**

I. INTRODUCTION

As the percentage of renewable energy generation increases on the electrical grid, energy storage can help smooth fluctuations in power generation from variable sources such as wind and solar. These can be large utility-scale installations or, depending on electricity rate structures, small energy storage installations installed in an individual home or business. Due in part to significant developments in the mobile electronics and automotive industry, Li-ion batteries at present hold cost, performance, energy/power density and lifetime advantages over other electrochemical battery chemistries.

Like all battery chemistries, Li-ion degrades with each charge and discharge cycle. Cycle life can be maximized by maintaining battery temperature near room temperature but drops significantly at high and low temperature extremes. Cycle life is also dependent on depth-of-discharge (DOD) and current, or C-rate. While it is common to discuss Li-ion lifetime in terms of number of cycles, often the calendar life of the cell is more limiting than cycle life. Detrimental side reactions occur within the cell even during storage. The rate of these deleterious side reactions increases with high temperature and high SOC. The electrochemical literature provides theoretical models of some individual mechanisms including side reactions impacting calendar life [1], cycling-driven electrode stress [2] and fracture [3], as well as coupling of calendar and cycling mechanisms [4]. The physics models are complex however, and not all degradation mechanisms are fully understood. As a result, the industry mainly uses semi-empirical lifetime models with varying range of complexity and accuracy [5-8]. These models extrapolate component-level accelerated aging test data to real-world lifetime scenarios.

As renewable power and energy storage industries work to optimize utilization and lifecycle value of battery energy storage, life predictive modeling becomes increasingly important. Typically, end-of-life (EOL) is defined when the battery degrades to a point where only 70-80% of beginning-of-life (BOL) capacity is remaining under nameplate conditions. Understanding temperature impact on battery performance is equally important to understanding degradation performance from a control or energy dispatch perspective. A battery's capacity at 0°C, may be just 70% of that under nameplate conditions.

Under a cooperative research and development agreement with SunPower, NREL characterized the thermal and aging performance of commercial Li-ion cells with graphite negative and NMC positive electrodes. A thermal/life prognostic model is developed based on the experimental data from those tests. The model is used to extrapolate lifetime for an application where the battery energy storage system is integrated with renewable PV power generation.

II. CELL AGING EXPERIMENTS

Eleven 75-Ah Kokam cells were tested under nine different aging conditions (Table I). Cells were fully charged at constant current to 4.2V followed by constant voltage until current tapered to less than C/10. Cells were fully discharged at constant current to a minimum voltage limit of 3.0V. The 4.2V/3.0V max/min voltage range for 100% DOD aging tests was narrowed to 4.1V/3.4V for 80% DOD tests. All aging tests were interrupted once per month to run a reference performance test (RPT), nominally a full capacity measurement at the C/5 rate and resistance measurement via the hybrid pulse power characterization (HPPC) test procedure [9]. All RPTs were run at the aging test temperature, except for cell 11, 55oC storage, whose RPT temperature was lowered to 45oC to respect manufacturer temperature limits during charging. Two conditions included

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TABLE I. AGING TESTS FOR KOKAM 75-AH CELL

Test #	Cycling tests				
	Temperature	***DOD***	***Dis./charge rate***	***Duty-cycle***[a]	***# of cells***
1,2	23°C	80%	1C/1C	100%	2
3	30°C	100%	1C/1C	100%	1
4	30°C	80%	1C/1C	50%	1
6,7	0°C	80%	1C/0.3C	100%	2
9	45°C	80%	1C/1C	100%	1
Test #	**Storage tests**				
	Temperature	***SOC***			***# of cells***
5	30°C	100%			1
8	45°C	65%			1
10	45°C	100%			1
11	55°C	100%			1

a. Fraction of cycling time to total time

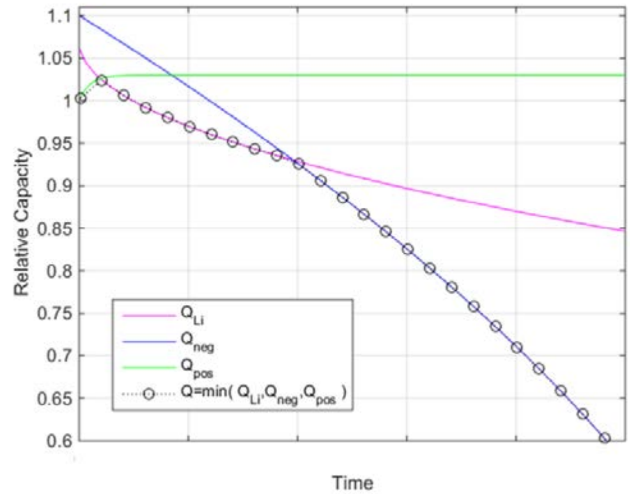

Fig. 1. Battery capacity as the minimum of three limiting mechanisms.

replicate cells. Under room temperature cycling with minimal fade, replicate cells 1 and 2 aged nearly identically to one another. Cells 6 and 7, aged at 0°C and experiencing severe fade, showed around 10% difference in fade rate.

III. CAPACITY FADE MODEL

A life model including reversible thermal effects on performance is developed describing the cell's capacity as measured at the C/5 rate as it varies with temperature, state-of-charge (SOC), depth-of-discharge (DOD), calendar time, and number of cycles. The approach follows previous battery life modeling framework [8] where capacity is controlled by the limiting of several competing degradation mechanisms. Amp-hour capacity directly relates to the number of moles of lithium (Li) that are shuttled between the negative and positive electrodes during discharge or charge of the battery. In rough order of importance, capacity changes over lifetime for the Kokam cell are due to three mechanisms:

1. Cyclable Li is consumed due to a solid-electrolyte interface (SEI) growth side reaction with time, coupled with electrode mechanical damage due to cycling
2. Negative electrode active sites that store cyclable Li are lost due to mechanical damage with cycling
3. Positive electrode active sites that store cyclable Li are gained due to increased surface area/electrolyte wetting during initial cycles, increasing the capacity that the positive electrode can hold with initial cycling. (Note that this phenomenon is much smaller than the other two and is only evident at BOL.)

Provided the battery is not severely cycled, the first mechanism, SEI growth, generally dominates in real-world aging conditions. Growth of the SEI accelerates with high average temperature and high average SOC. Generally the second mechanism, loss of electrode sites, outpaces the first mechanism under low temperatures, high DODs, C-rates, and/or frequent cycling greater than, e.g., 4 cycles per day. Cycle life aging tests, particularly at low temperature, follow this limiting mechanism.

Development of the model from capacity and resistance aging data follows previous work [8]. Measured Amp-hour capacity, Q, is taken to be the minimum of Li-limited capacity Q_{Li}, negative electrode-site-limited capacity Q_{neg}, or positive electrode-site-limited capacity Q_{pos}.

$$Q = \min\left(Q_{Li}, Q_{neg}, Q_{pos}\right) \tag{1}$$

Fig. 1 shows an example how these three separate mechanisms can interact to each separately control capacity. Capacity on the y-axis is relative to BOL nameplate. during different portions of the battery's life. Many other combinations of these mechanisms and thus fade patterns are also possible depending on the aging condition.Model equations below use common reference constants T_{ref} = 298.15 K, V_{ref} = 3.7 V, and $U_{-,ref}$ = 0.08 V, Faraday constant F = 96485 A s mol^{-1}, and universal gas constant R_{ug} = 8.314 J K^{-1} mol^{-1}.

A. Beginning-of-Life Capacity Increase & Temperature Dependence

First we consider battery capacity at BOL, assumed to be controlled by positive electrode-site-limited capacity, Q_{pos}. Fig. 2 shows data for the first several cycles of the aging test. Temperature is the main factor controlling capacity at BOL. Capacity increases a small amount, on the order of 0.5%, over the first cycles. These two effects are captured mathematically as:

$$Q_{pos} = d_0 + \underbrace{d_3\left(1-\exp(-Ah_{dis}/228)\right)}_{\text{Increase in capacity at BOL}} \tag{2}$$

$$d_0 = d_{0,ref}\left(\exp\left[-\frac{E_{a,d_0,1}}{R_{ug}}\left(\frac{1}{T_{RPT}(t)}-\frac{1}{T_{ref}}\right)-\left(\frac{E_{a,d_0,2}}{R_{ug}}\right)^2\left(\frac{1}{T_{RPT}(t)}-\frac{1}{T_{ref}}\right)^2\right]\right) \tag{3}$$

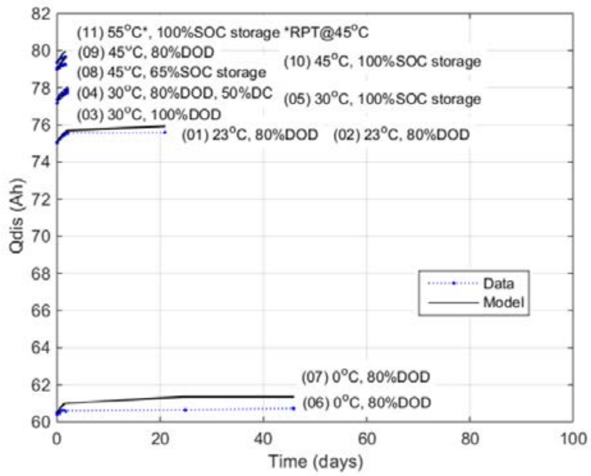

Fig. 2. Initial capacity described by positive electrode-site-limited capacity model.

where Ah_{dis} is the cumulative Amp-hours discharged from the cell. The remaining parameters are fit using the nonlinear least-squares function `nlinfit` in Matlab©, with values of d_3 = 0.46 Ah, $d_{0,ref}$ = 75.10 Ah, $E_{a,d0,1}$=34300 J mol^{-1}, and $E_{a,d0,2}$ = 74860 J mol^{-1} providing the best fit.

A. Calendar Life Capacity Fade with Mild Dependence on Cycling

Next, we consider the Li-limited capacity, Q_{Li}, generally exhibited under storage aging conditions, but also for mild-to-moderate cycling conditions where capacity fade rate decelerates with time and does not experience sudden fade. All Li-ion batteries with graphite or carbon negative electrodes lose Li due to a SEI growth side reaction. The side reaction is generally diffusion limited and therefore proceeds with the square root of time. Individual storage capacity fade test conditions dominated by this diffusion-limited side reaction can be described using a model of the form $b_0 + b_1 t^{1/2}$. For the present cell, two additional terms must also be included to account for Li loss proportional to cycling and a small loss of Li at BOL as the cell is broken in. With these three Li loss mechanisms, the model is

$$Q_{Li} = d_0 \left[b_0 - \underbrace{b_1 t^{1/2}}_{\text{SEI growth with calendar time}} - \underbrace{b_2 N}_{\text{Loss with cycling}} - \underbrace{b_3 \left(1 - \exp(-t/\tau_{b3})\right)}_{\text{Break-in mechanism at BOL}} \right] \quad (4)$$

In this Li loss model, d_0 captures temperature dependence of initial capacity as previously described. Coefficients b_1, b_2, and b_3 are dependent on the aging condition as follows:

$$b_1 = b_{1,ref} \exp\left[-\frac{E_{a,b_1}}{R_{ug}}\left(\frac{1}{T(t)} - \frac{1}{T_{ref}}\right)\right] \exp\left[\frac{\alpha_{b_1} F}{R_{ug}}\left(\frac{U_{-}(t)}{T(t)} - \frac{U_{ref}}{T_{ref}}\right)\right] \exp\left[\gamma_{b_1} (DOD_{\max})^{\beta_{b1}}\right] \quad (5)$$

$$b_2 = b_{2,ref} \exp\left[-\frac{E_{a,b_2}}{R_{ug}}\left(\frac{1}{T(t)} - \frac{1}{T_{ref}}\right)\right] \quad (6)$$

$$b_3 = b_{3,ref} \exp\left[-\frac{E_{a,b_3}}{R_{ug}}\left(\frac{1}{T(t)} - \frac{1}{T_{ref}}\right)\right] \exp\left[\frac{\alpha_{b_3} F}{R_{ug}}\left(\frac{V_{OC}(t)}{T(t)} - \frac{V_{ref}}{T_{ref}}\right)\right] \left(1 + \theta\, DOD_{\max}\right) \quad (7)$$

The data show that high or low average temperature, high average SOC and high maximum DOD all accelerate Li-loss capacity fade. High temperature and SOC both accelerate the SEI growth side reaction. Deep cycling mechanically disturbs the SEI, creating fresh electrode surface area where new SEI can form. This mechanical damage can also be accelerated by low temperature.

Li-loss model parameters are fit mostly in a sequential fashion following dominant trends in the data as described below. However, small iterative adjustments are made along the way to improve overall quality of fit.

1. First, a simple model $y = y_0 - b_1 t^{1/2}$ is fit only to storage aging data (DOD_{max} = 0) for data after 50 days of aging, providing parameters $b_{1,ref}$ = 3.503e-3 day$^{-0.5}$, $E_{a,b1}$ = 35392 J mol^{-1} and α_{b1} = 1.0.
2. Next, the simple model is also fit to moderate cycling conditions that follow the square root of time fade trajectory, providing parameters γ = 2.472 and β_{b1} = 2.157.
3. Fitting the simple model $y = y_0 - b_1 t^{1/2}$ to data beyond the first 50 days showed that the y-intercept, y_0, varied with temperature and DOD. This motivated the inclusion of the break-in mechanism model. Fitted parameters are b_0 = 1.07, $b_{3,ref}$ = 2.805e-2, $E_{a,b3}$ = 42800 J mol^{-1}, α_{b3} = 0.0066, τ_{b3} = 5, and θ = 0.135.
4. Initially neglecting the b_2 term, model error increased proportionally with number of cycles, motivating the inclusion of the cycling dependent term. Including this term in the model with parameters $b_{2,ref}$ = 1.541e-5 and $E_{a,b2}$ = –42800 J mol^{-1} improved the quality of fit.

Fig. 3 shows a comparison of the model with data. The model matches all cases well except 0°C cycling conditions for which the model under predicts capacity fade after 200 days. (In the following section, those under-predicted aging conditions are captured by including an additional negative electrode site loss mechanism.) Excluding the 0°C test cases, the model has a quality of fit of R^2 = 0.97 and root mean square error, RMSE = 0.77 Ah, or an average error of 1.0% relative to the cell's 75-Ah nameplate capacity.

B. Cycle Life Model

Active sites may be lost from both electrodes due to expansion and contraction of the Li host materials during charge and discharge cycling causing mechanical stress and fatigue. The graphite negative electrode expands up to 8% during a full discharge. The NMC positive electrode expands on the order of 2%; hence, the loss of negative electrode active sites is assumed to outpace the positive.

The negative electrode site-loss model assumes that the site capacity lost with each cycle, N, is inversely proportional to the amount of remaining sites. In other words, as sites are lost, the remaining sites are stressed more and more in order to maintain the same duty cycle,

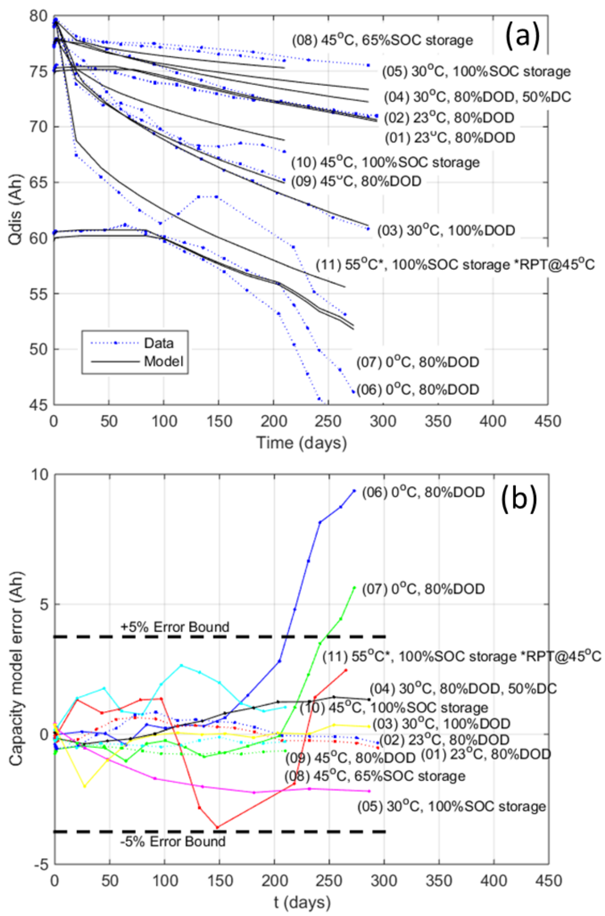

Fig. 3. Positive- and Li-limited capacity fade model. (a) Model versus data. (b) Model error.

$$\frac{dQ_{neg}}{dN} = -\left(\frac{c_2}{Q_{neg}}\right). \tag{8}$$

The analytical solution to this ordinary differential equation is:

$$Q_{neg} = \left[c_0^{\ 2} - 2c_2c_0\ N\right]^{\frac{1}{2}} \tag{9}$$

Coefficient c_0 represents the initial negative electrode site capacity. Rate of capacity loss per cycle, c_2, is dependent on temperature, DOD, and C-rate. Too little data are available here to separately characterize C-rate and DOD effects, however based on previous experience, DOD is the dominant effect. The present rate model captures temperature and DOD dependence

$$c_2 = c_{2,ref}\ \exp\left[-\frac{E_{a,c_2}}{R_{ug}}\left(\frac{1}{T(t)} - \frac{1}{T_{ref}}\right)\right]\left(DOD\right)^{\beta_{c2}} \tag{10}$$

Data beyond 170 days for 0°C and 23°C are used to fit the negative electrode site loss model, providing $c_{2,ref}$= 3.9193e-3 Ah cycle^{-1}, β_{c2} = 4.54, and $E_{a,c2}$ = –48260 J mol^{-1}. The initial negative site capacity, c_0 also shows slight temperature dependence fitted with parameters $c_{0,ref}$ = 75.64 Ah and $E_{a,c0}$ = 2224 J mol^{-1}.

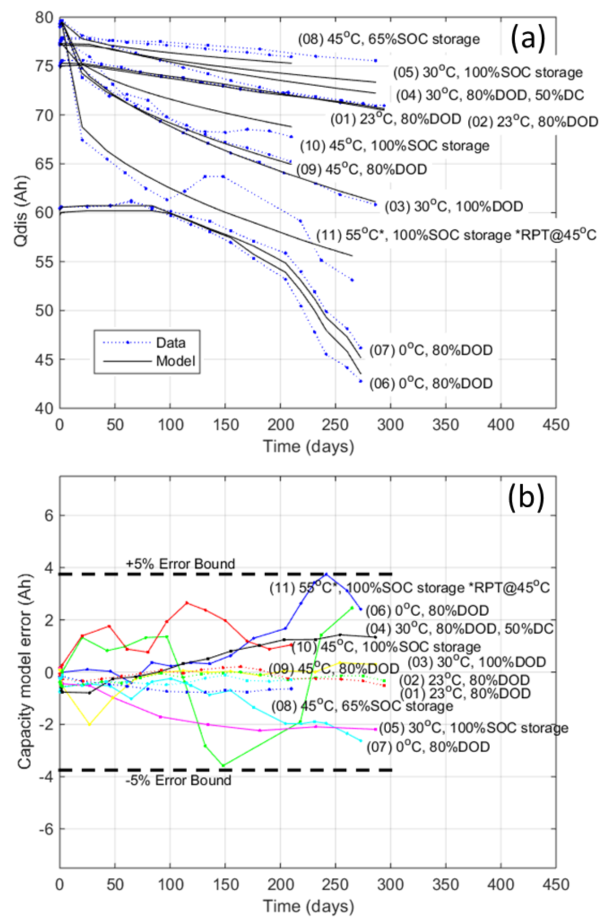

Fig. 4. Final capacity fade model, incorporating positive-, negative-, and Li-limiting mechanisms. (a) Model versus data. (b) Model error.

$$c_0 = c_{0,ref}\ \exp\left[-\frac{E_{a,c0}}{R_{ug}}\left(\frac{1}{T(t)} - \frac{1}{T_{ref}}\right)\right] \tag{11}$$

Fig. 4 shows the final capacity fade model, with R^2=0.99 and RMSE of 1.05 Ah, or 1.4% of nameplate. The cases with largest model error are those with the most fade. For cell 11 aged under storage at 55°C, the model slightly under-predicts fade. For 0°C cycling, cells 6 and 7, the model falls between the fade experienced by the two replicate cells. Cell 6 fade is slightly under-predicted; Cell 7 is slightly over-predicted. Fade is predicted within ±5% error bounds for all cells.

IV. Resistance Model

Additional model equations are developed and parameterized describing cell resistance at 50% SOC for a 10-second pulse discharge, as it evolved over the course of the cell aging tests. Similar to the capacity fade model, the resistance growth model captures resistance changes with temperature, SOC, DOD, calendar time and number of cycles. Mechanisms contributing to resistance changes are

0. Temperature dependence at BOL
1. SEI layer growth, creating a resistive film at the surface of the negative electrode, with resistance growth proportional to square-root of calendar time
2. Loss of negative electrode active sites as modeled in the previous capacity fade model
3. Break-in mechanism causing initial decrease in resistance, presumably due to microfracture of electrodes surfaces and/or increased electrolyte wetting early in life, both leading to an increase in electrode surface area
4. Increase in resistance proportional to calendar time, possibly related to degradation at the positive electrode surface.

These mechanisms are modeled as:

$$R = \underbrace{R_0}_{\substack{\text{Instantateous}\\ \text{temperature}\\ \text{response}}} \left[\underbrace{a_0}_{\substack{\text{Base}\\ \text{resistance}}} + \underbrace{a_1 t^{1/2}}_{\substack{\text{SEI growth}\\ \text{with calendar}\\ \text{time}}} + \underbrace{a_2 / Q_{neg}}_{\substack{\text{Loss with}\\ \text{cycling (using}\\ \text{negative site}\\ \text{loss model)}}} - \underbrace{a_3 \left(1 - \exp(-t/\tau_{a3})\right)}_{\substack{\text{Break-in mechanism}\\ \text{at BOL}}} + \underbrace{a_4 t.}_{\substack{\text{Secondary}\\ \text{calendar life}\\ \text{term proportional}\\ \text{to time}}} \right]. \qquad (12)$$

As the capacity fade model was developed in the previous section, different portions of the capacity dataset were segregated and separate models were developed for different limiting mechanisms. For the resistance growth model, however, all degradation mechanisms contribute simultaneously in an additive manner and individual model parameters are more difficult to isolate. The model contains too many parameters to fit all of them at once. Instead, a sequential process was used. Terms 0–2 were fit first. Following this first step, it became evident that a break-in mechanism decreasing resistance was in play, reducing resistance by approximately 0.2 mΩ at room temperature over the first 100 days. Adding this mechanism and refitting the model with terms 0–3, it became evident that resistance also increased proportional to time, requiring the secondary calendar life term, 4. With all terms 0–5 in place, final minor adjustments were made to the rate constants to improve the overall fit.

Rate equations for the final model are:

$$R_0 = R_{0,ref} \exp\left[-\frac{E_{a,r_0}}{R_{ug}} \left(\frac{1}{T_{RPT}(t)} - \frac{1}{T_{ref}} \right) \right]) \qquad (13)$$

with parameters $R_{0,ref}$ = 1.155e-3 Ω, $E_{a,R0}$ = -28640 J mol^{-1}

$$a_0 = a_{0,1} \exp\left[-\frac{E_{a,a_{0,1}}}{R_{ug}} \left(\frac{1}{T_{RPT}(t)} - \frac{1}{T_{ref}} \right) \right] + a_{0,2} \exp\left[-\frac{E_{a,a_{0,2}}}{R_{ug}} \left(\frac{1}{T_{RPT}(t)} - \frac{1}{T_{ref}} \right) \right]) \qquad (14)$$

with parameters $a_{0,1}$ = 0.442, $a_{0,2}$ = -0.199, $E_{a,a0,1}$ = 28640 J mol^{-1}, $E_{a,a0,2}$ = -46010 J mol^{-1},

$$a_1 = a_{1,ref} \exp\left[-\frac{E_{a,a_1}}{R_{ug}} \left(\frac{1}{T(t)} - \frac{1}{T_{ref}} \right) \right] \exp\left[\frac{\alpha_{a_1} F}{R_{ug}} \left(\frac{U\_(t)}{T(t)} - \frac{U_{ref}}{T_{ref}} \right) \right] \exp\left[\gamma_{a_1} (DOD_{\max})^{\beta_{a1}} \right] \qquad (15)$$

with parameters $a_{1,ref}$ = 0.0134 day$^{-1/2}$, $E_{a,a1}$ = 36100 J mol^{-1}, α_{a1} = -1.0, γ_{a1} = 2.433, β_{a1} = 1.870,

$$a_2 = a_{2,ref} \exp\left[-\frac{E_{a,a_2}}{R_{ug}} \left(\frac{1}{T(t)} - \frac{1}{T_{ref}} \right) \right] \qquad (16)$$

with parameters $a_{2,ref}$ = 46.05 Ah, $E_{a,a2}$ = -29360 J mol^{-1},

$$a_3 = a_{3,ref} \exp\left[-\frac{E_{a,a_3}}{R_{ug}} \left(\frac{1}{T(t)} - \frac{1}{T_{ref}} \right) \right] \qquad (17)$$

with parameters $a_{3,ref}$ = 0.145, $E_{a,a3}$ = -29360 J mol^{-1}, τ_{a3} = 100 days, and:

$$a_4 = a_{4,ref} \exp\left[-\frac{E_{a,a_4}}{R_{ug}} \left(\frac{1}{T(t)} - \frac{1}{T_{ref}} \right) \right] \exp\left[\frac{\alpha_{a_4} F}{R_{ug}} \left(\frac{U\_(t)}{T(t)} - \frac{U_{ref}}{T_{ref}} \right) \right] \qquad (18)$$

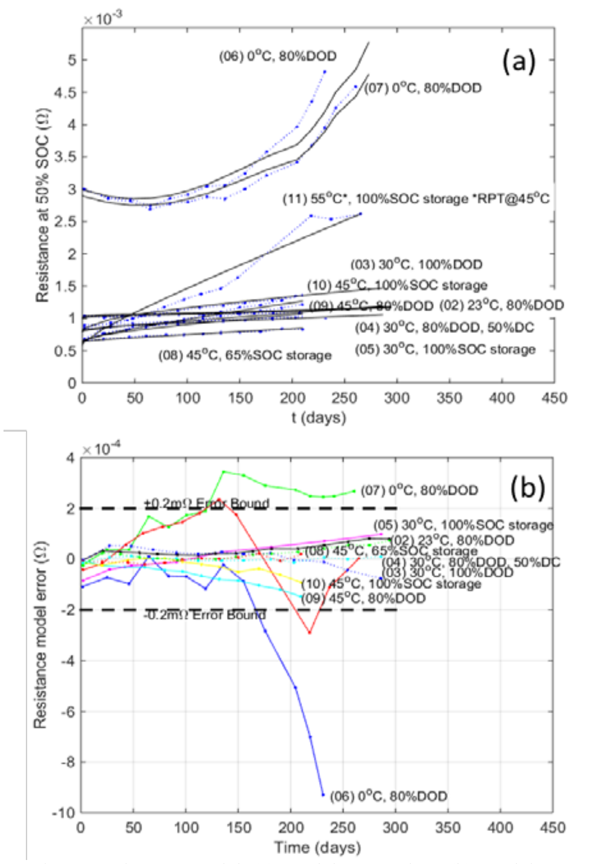

Fig. 5. Resistance model. (a) Model versus data. (b) Model error.

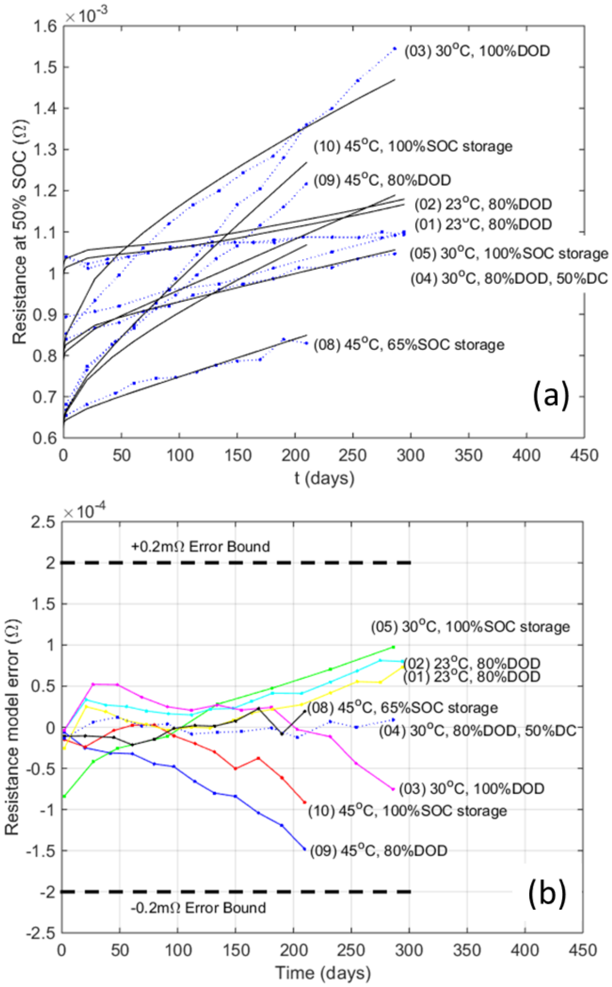

Fig. 6. Resistance model versus all data except the most severe fade cases at 0°C and 55°C. (a) Model versus data. (b) Model error.

with parameters $a_{4,ref}$ = 5.357e-4 day^{-1}, $E_{a,a4}$ = 77470 J mol^{-1} and α_{a4} = -1.0.

Fig. 5 shows the resistance model together with data for all 13 cell tests. The model has quality of fit R^2 = 0.98. Root-mean-square error is 0.15 mΩ, which is 15% of the cell's nameplate 1-mΩ resistance at room temperature and BOL. The largest model error is for cells that aged at 0°C or 55°C and experienced the most significant fade.

Fig. 6 shows the resistance model against all data except the 0°C and 55°C severe aging cases. Within this subset of moderate aging conditions the model has quality of fit R^2 = 0.96. Root-mean-square error is 0.044 mΩ, which is 4.4% of the cell's nameplate resistance.

V. Simulation of Grid Storage Applications

For simulation of variable temperature, variable cycling scenarios, the model is recast in state variable form [8]. The model has eight states, with equations (2), (4), (8) and (12) contributing 1,3,1 and 4 states respectively. Here, example simulation results are given for capacity degradation of the battery in a PV-battery integrated system operating in self-consumption mode. In this mode, the inverter attempts to

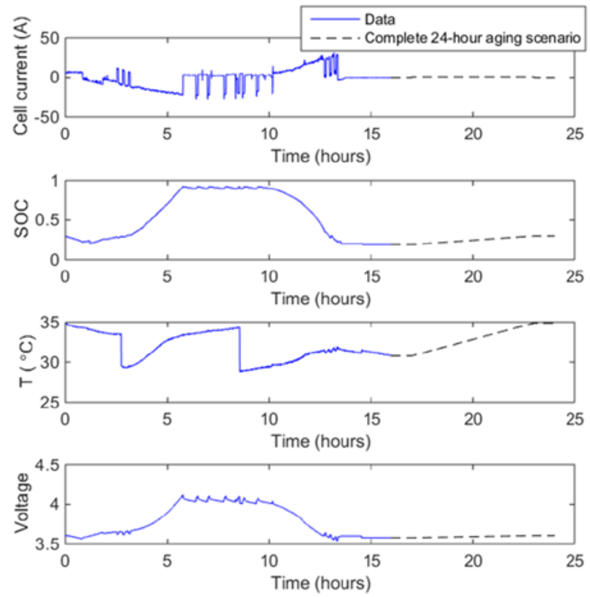

Fig. 7. Battery response when integrated with PV system operating in self-consumption mode. Synthetic data was added to experimental data to complete a 24-hour scenario for purposes of battery aging simulation.

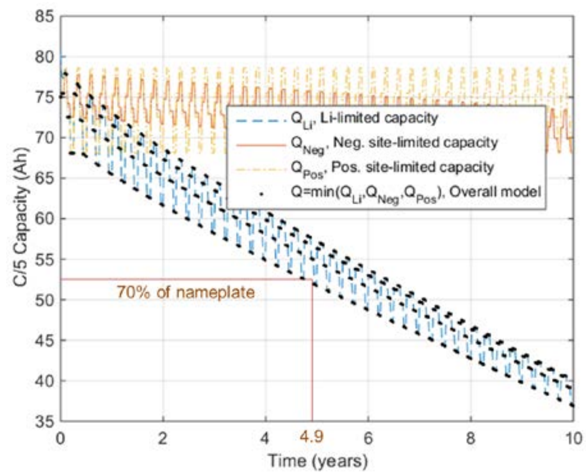

Fig. 8. Simulated battery capacity fade under self-consumption mode operation with seasonal ambient temperature variation of 18/28/12/5ºC for spring/summer/fall/winter seasons, respectively.

serve local loads using only PV and/or battery as long as possible until an SOC limit is reached. Other battery/PV modes of operation and experimental test results are explored in [10].

Figure 7 shows experimental data of battery cell response to self-consumption mode power profile with 28°C ambient temperature. Key factors impacting battery degradation rate are battery average temperature of 32°C, average SOC of 45%, maximum DOD of 74%, and daily Amp-hour throughput of 69 Ah (discharge direction, with positive current). Assuming repeated cycling in this mode for 365 days/year, the battery lasts 7.3 years to 70% of 75Ah name-

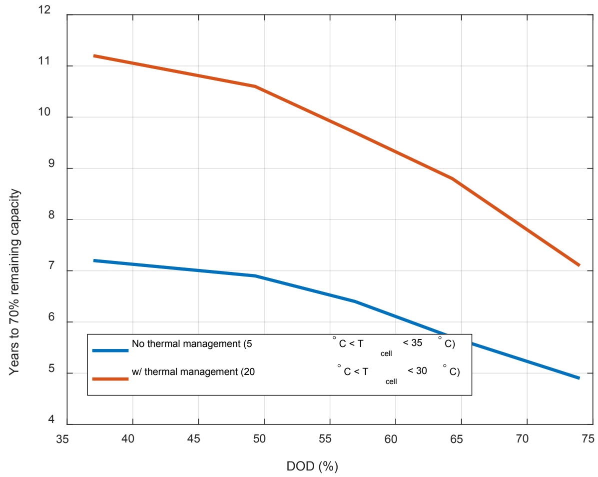

Fig. 9. Impact of battery oversizing and thermal management on lifetime.

plate. In the case the battery is mounted outside a building, it will be exposed to ambient temperature variation. Cell-to-cell aging inhomogeneity due to temperature gradients and aging process non-uniformity are neglected.

Figure 8 shows a simulated aging result with seasonal ambient temperature variation of 18/28/12/5^{o}C representing spring, summer, fall and winter seasons, respectively, together with modest cell temperature rise. The cold temperatures impose additional degradation compared to the constant 28^{o}C ambient temperature. In this case, the battery lasts 4.9 years until it degrades to 70% of nameplate capacity. The battery first falls below this performance threshold during a winter season.

The utility of the simulation model is that it enables rapid exploration of multiple system design and control scenarios. Two methods to extend lifetime include (1) oversizing the battery and thereby restricting its maximum daily DOD and (2) adding battery thermal management. These tradeoffs are shown in Figure 9. Daily average SOC is maintained at 45% across all cases. The SOC operating range is narrowed at the maximum and minimum extremes to sweep DOD. In the case of no thermal management, battery temperature varies with outside ambient temperature, heat generation and heat dissipation rate. The impact is that cell temperatures swing from 5^{o}C in the winter to 35^{o}C in the summer. In this case it is only possible to get 7 years life out of the battery using it within a restricted 47% DOD operating range. If a thermal management system were added to maintain battery cell temperatures within a 20-30^{o}C operating range year-round, the battery life is extended from 4.9 years to 7.0 years cycling the battery at 74% DOD. Life is improved to 10 years using the same thermal management and further restricting DOD to 54%. The cost/benefit of oversizing the battery versus adding thermal management can readily be quantified versus the cost/benefit of importing/exporting electricity from/to the grid.

VI. Conclusion

A battery life prognostic model was identified from 9 cell accelerated aging experiments conducted on 11 cells over 300 days at temperatures ranging from 0^{o}C to 55^{o}C and DODs ranging from storage to 100% DOD. Model error increases with the magnitude of fade and further efforts are desired to improve model accuracy and validate the model versus untested aging conditions, including long-term, real-world aging in the field. Model error, averaging 1.4% of capacity and 15% of resistance, is nonetheless reasonably low that the model is valuable to provide tradeoffs in battery lifetime for different battery system designs and operating scenarios for energy storage integrated with renewable power generation. An example scenario was simulated wherein an integrated battery-PV system was controlled in self-consumption mode, attempting to minimize energy exchanged with the grid. For this application, battery lifetimes ranging from 7-10 years may be expected. Without active thermal management, 7 years lifetime is possible provided the battery is cycled within a restricted 47% DOD operating range. With active thermal management, 10 years lifetime is possible provided the battery is cycled within a restricted 54% operating range. Together with battery capital cost and electricity cost, the life model can be used to optimize the overall life-cycle benefit of integrating battery energy storage on the grid.

Acknowledgment

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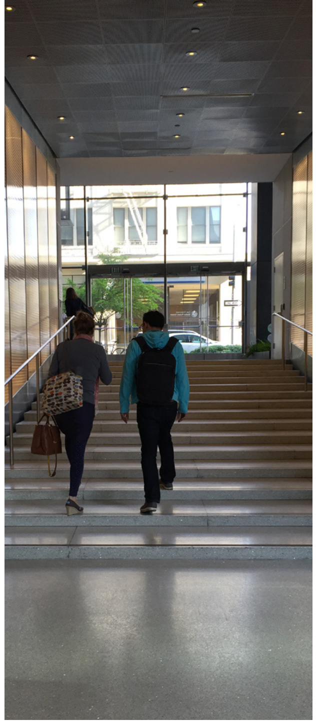
San Francisco
CLEAN CONSTRUCTION ORDINANCE

Implementation Guide for San Francisco Public Projects

FINAL
AUGUST 2015

San Francisco Department of the Environment
San Francisco Department of Public Health
San Francisco Planning Department



San Francisco Planning

SF Environment
Our home. Our city. Our planet.
A Department of the City and County of San Francisco

SFDPH Environmental HEALTH
improving environments
protecting health

Table of Contents

In April 2007, the City and County of San Francisco adopted an Ordinance requiring public projects to reduce emissions at construction sites starting in 2009. In March 2015, the City expanded the existing Ordinance to require public projects to further reduce emissions at construction sites in certain areas with high levels of background concentrations of air pollutants.

This guide describes the City's process for implementing the requirements of the expanded Clean Construction Ordinance, and resources to assist City Departments in meeting these requirements.

This guide provides an introduction to the Clean Construction requirements, describes health effects of common air pollutants, presents off-road (i.e., construction) equipment basics, describes the Clean Construction implementation process, provides a template of a Construction Emissions Minimization Plan, and presents additional resources and funding opportunities for upgrading equipment.

The San Francisco Clean Construction Ordinance is available at:

https://sfgov.legistar.com/Legislation.aspx (Board File Nos. 140805 AND 150526 or Ordinance No. 28-15)

This guide only applies to the Clean Construction Ordinance. Agencies and contractors are responsible for understanding other City regulations that apply to air quality such as:

- Construction Dust Control Requirements https://www.sfdph.org/dph/EH/Air/Dust.asp
- Enhanced Ventilation Requirements https://www.sfdph.org/dph/EH/Air/Article38.asp
- Maher Ordinance Requirements https://www.sfdph.org/dph/EH/HazWaste/hazWasteSiteMitigation.asp

Introduction to the Clean Construction Ordinance

The City and County of San Francisco has long been a leader in protecting residents' public health. In a dense, urban center like San Francisco, construction sites can be located in areas of the City with high levels of background concentrations of air pollutants (Air Pollutant Exposure Zone, see page 3 Figure 2). In addition, these locations may be located close to sensitive uses, such as children and the elderly, who are more susceptible to the negative effects of air pollutants such as diesel particulate matter. According to the California Air Resources Board, off-road equipment such as construction equipment is the sixth largest source of diesel particulate matter emissions in California and can cause a public health risk and nuisance to sensitive populations.

Through the implementation of the requirements of the Clean Construction Ordinance, contractors for publicly-funded construction projects can substantially reduce their emissions and the associated public health risk at construction sites.

The Clean Construction Ordinance shall become operative on September 6, 2015, and shall apply to all contracts first advertised or initiated on or after this date. The Clean Construction Ordinance contains the following requirements for project sites in the Air Pollutant Exposure Zone (See Table 1 below and page 8 for requirements outside of the Air Pollutant Exposure Zone) :

1. Equipment Requirements:

    - Use Tier 2 or higher engines **and** the most effective Verified Diesel Emission Control Strategies (VDECS) available for the engine type (Tier 4 engines automatically meet this requirement) as certified by the California Air Resources Board (ARB);
    - Prohibit portable diesel engines where access to alternative sources of power are available;
    - Restrict idling to two minutes; and
    - Properly maintain and tune equipment in accordance with manufacturer specifications.

2. Construction Emissions Minimization Plan (Emissions Plan) shall be prepared and include the following:

    - An equipment inventory which shall include estimates of the construction timeline by phase with description of each piece of off-road equipment required for each phase (See page 9);
    - Signage indicating idling limits and engine/ Verified Diesel Emission Control Strategies requirements (See page 11); and
    - Certification Statement (See page 12).

3. Monitoring shall begin at the start of construction activities and include:

    - Quarterly reports documenting compliance with the Emissions Plan which shall be maintained at the project site; and
    - Final report summarizing construction activities.

Required documents must be submitted to the head of the department (Department Head) funding the public project (e.g. San Francisco Public Works, San Francisco Public Utilities Commision, San Francisco Port, etc.). The Department Head is responsible for ensuring that all requirements of the Clean Construction Ordinance are met by the Contractor.

How do I...

...check if my project site is in the Air Pollutant Exposure Zone? See Page 3

...figure out how the Clean Construction Ordinance applies to my project? See Page 8

Table 1: Summary of Clean Construction Ordinance

	Outside Air Pollutant Exposure Zone	Within Air Pollutant Exposure Zone
Code	Administrative and Environment	Same
Applicability	Public Projects > 20 days in length	Same
Standard Best Management Practices (BMPs)	Tier 2 **or** VDECS **and** B20 biodiesel Contract bids and specifications	Tier 2 **and** VDECS **and** Monitoring Plan Same
Enforcement	Individual City Departments	Same
Reporting/Technical Assistance	Department of Environment	Same
Waivers/Exceptions	Unavailability of equipment	Same

How do I…

…check if my project site is in the Air Pollutant Exposure Zone?

Access PIM (Figure 1) at: http://propertymap.sfplanning.org/?dept=planning

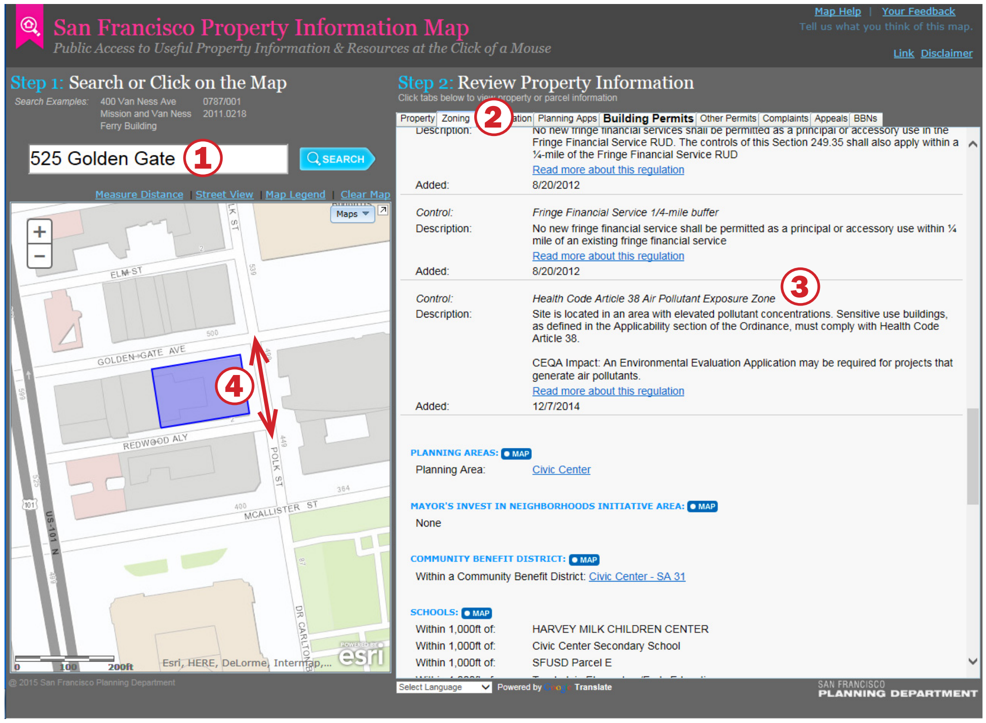
1 Enter address

2 Click on Zoning Tab

3 Check if in the APEZ

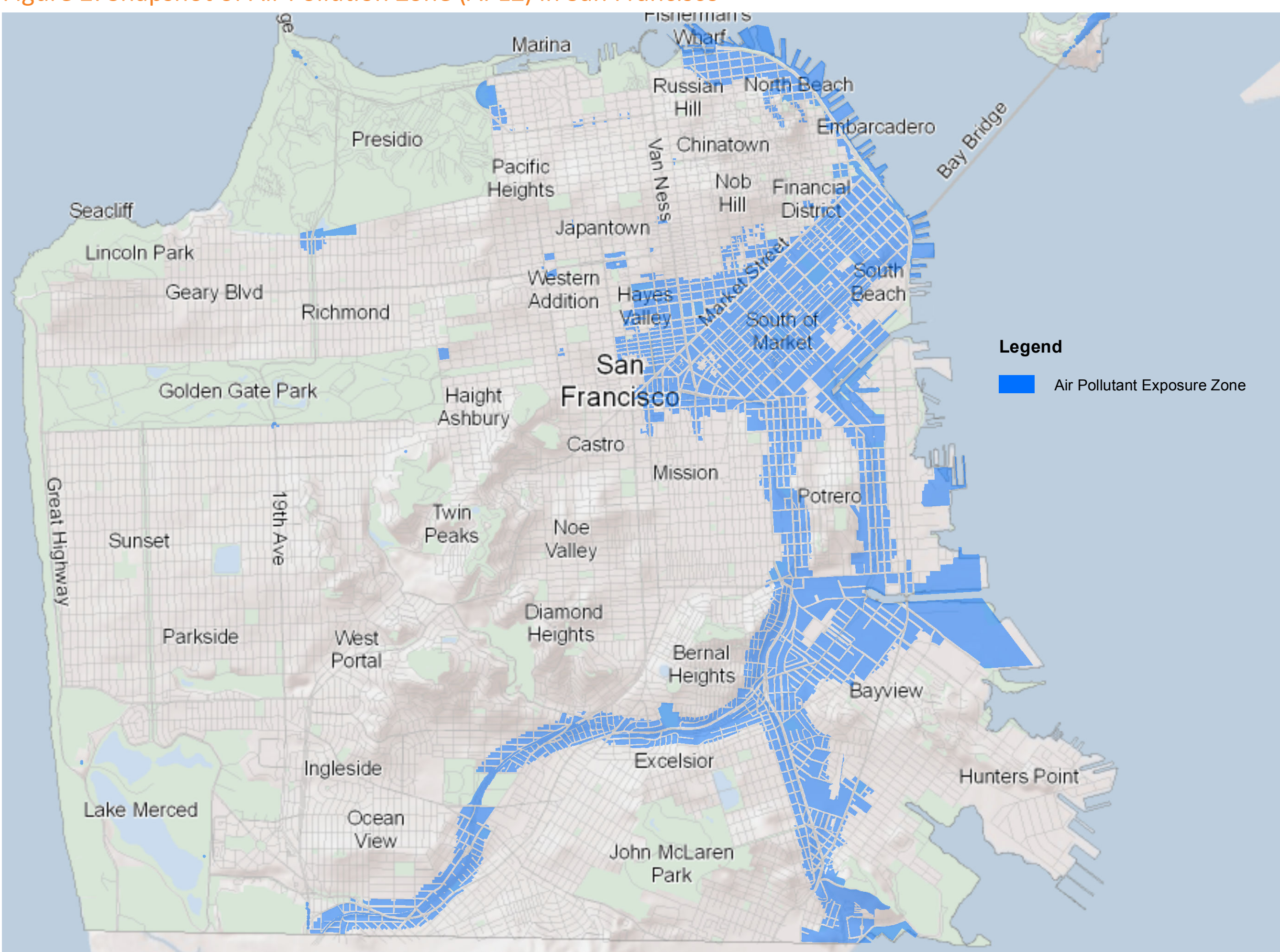
4 If public right-of-way project, check if adjacent parcel(s) in APEZ**

Figure 1: San Francisco Property Information Map (PIM)



** Note: only those portions of public right-of-way project that are within the APEZ are subject to the additional APEZ requirements.

Figure 2: Snapshot of Air Pollution Zone (APEZ) in San Francisco*

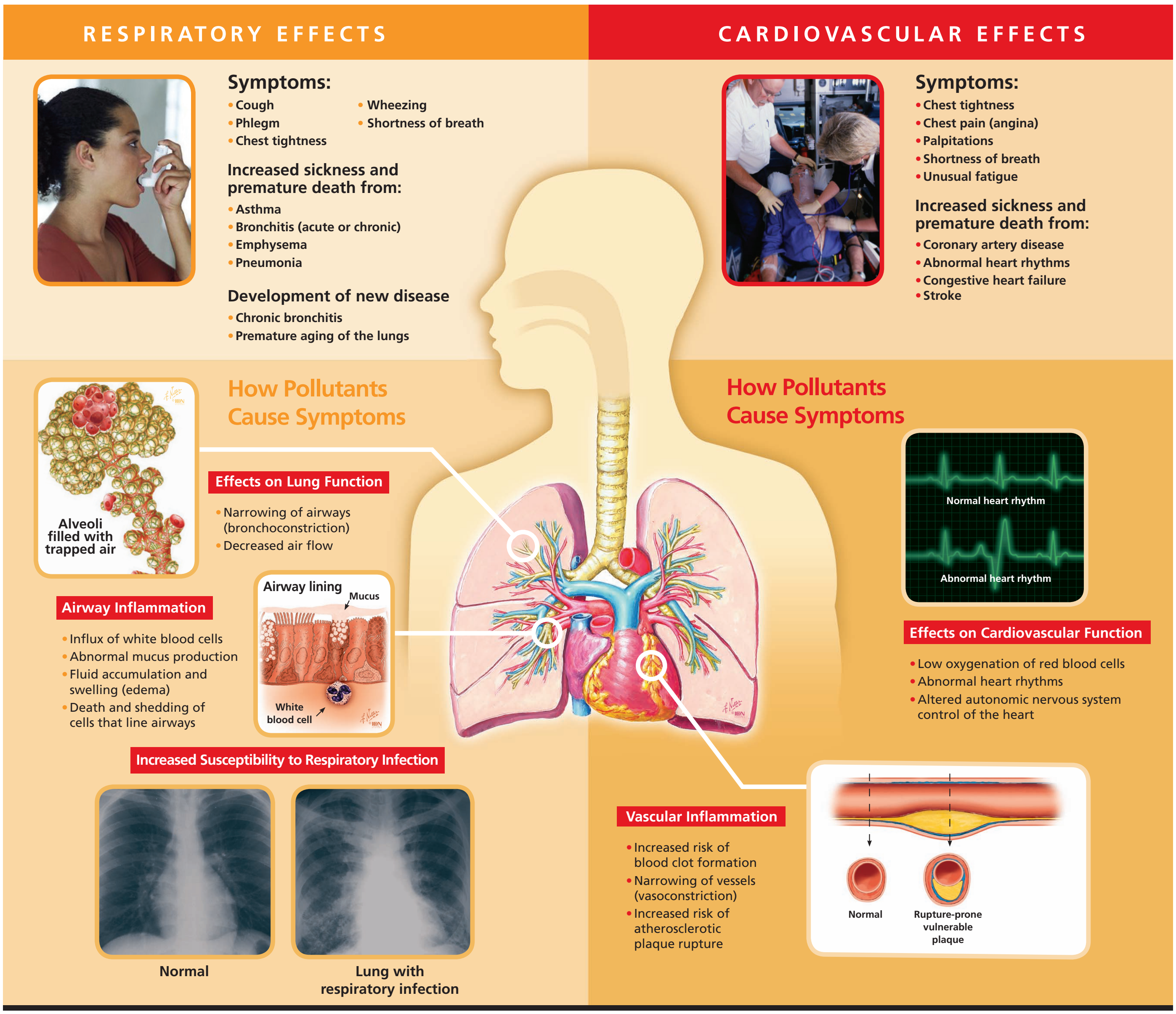


* Access official map with notes at: https://www.sfdph.org/dph/files/EHSdocs/AirQuality/AirPollutantExposureZoneMap.pdf

Health Impacts from Construction Activities

Construction activities produce emissions that affect air quality. Scientific studies have found an association between exposure to particulate matter and significant human health problems, including: aggravated asthma; chronic bronchitis; reduced lung function; irregular heartbeat; heart attacks; and premature death in people with heart or lung disease. Exposure to diesel exhaust is an established cause of lung cancer. The US Environmental Protection Agency (EPA) has recognized that air pollution affects the public's health, especially sensitive groups, and can result in respiratory and cardiovascular effects as shown in Figure 3 below.

Figure 3: Health Effects of Common Air Pollutants



http://www.epa.gov/airnow/health-prof/common-air-pollutants-2011-lo.pdf

Off-Road (Construction) Equipment Basics and Health Benefits

Project construction involves the use of off-road equipment such as bore/drill rigs, cranes, crawler tractors, excavators, graders, off-highway tractors, off-highway trucks, other construction equipment, pavers, paving equipment, rollers, rough terrain forklifts, rubber-tired dozers, rubber-tired loaders, scrapers, skid steer loaders, surfacing equipment, tractors/loaders/backhoes, and trenchers.

Engines

Prior to 1994, there were no standards (Tier 0) to limit the amount of emissions from off-road equipment. In 1994, the EPA established emission standards for hydrocarbons, nitrogen oxides, carbon monoxide, and particulate matter to regulate new pieces of off-road equipment. These emission standards came to be known as Tier 1. Since that time, more stringent Tier 2, Tier 3, and Tier 4 (interim and final) standards were adopted by the EPA, as well as ARB. Each adopted emission standard was phased in over time (as shown on Table 2 on page 6). New engines built in 2015 across all horsepower (hp) sizes have to meet Tier 4 final emission standards. In other words, new manufactured engines cannot exceed the emissions established for Tier 4 Final. Out of the estimated 161,420 pieces of construction equipment used statewide, 59% are Tier 2 and above. This means that more than half of the equipment utilized statewide are newer and cleaner engines. Refer to Figure 4 on page 6 which illustrates engine tier availability in California.

Verified Diesel Emission Control Strategies (VDECS)

As stated above, the emission standards only apply to new engines. However, off-road equipment can last several years, even prior to Tier 1 emission standards being established (approximately 21% of off-road equipment). Verified diesel emission control strategies (VDECS) help to further reduce emissions from existing engines. VDECS are designed primarily for the reduction of diesel particulate matter emissions and have been verified by the ARB. There are three levels of VDECS. The most effective VDECS (a device, system or strategy used to achieve the highest level of pollution control from an existing off-road vehicle) is the Level 3 VDECS. Tier 4 engines are not required to install VDECS since they already meet the emissions standards for lower tiered equipment with installed controls.

How do I...

...verify what level my engine is?

Contact: DOORS hotline at 877-593-6677 or Thien Tran* (Air Pollution Specialist at ARB) at 916-332-0517

...figure out what VDECS is appropriate for the different types of equipment and check the level of my VDECS?

Visit: http://www.arb.ca.gov/diesel/verdev/vt/cvt.htm

* contact as of June 2015

More Info: ARB In-Use Off-Road Diesel Vehicle Regulations

In July 2007, the ARB adopted the In-Use Off-Road Diesel Vehicle Regulation to reduce diesel particulate matter and oxides of nitrogen emissions from in-use existing off-road diesel vehicles in California. This regulation includes:

- Equipment labeling requirements
- Annual reporting of equipment
- Five minute (30 seconds 100 feet of schools) idling limit (applies to off-road and on-road diesel vehicles)
- Restrictions on adding older, and dirtier Tier 0 and Tier 1 vehicles to construction fleets.

For more information: http://arb.ca.gov/msprog/ordiesel/ordiesel.htm

Table 2: California Air Resources Board and United States Environmental Protection Agency Off-Road Compression-Ignition (Diesel) Engine Standards[a]

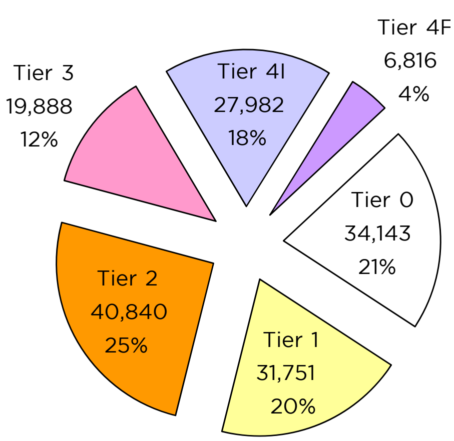
Maximum horsepower	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015+
25≤hp<50	-				7.1 /4.1 / 0.60					5.6 / 4.1 / 0.45				5.6 / 4.1 / 0.22					3.5 / 4.1 / 0.02		
50≤hp< 75	-			- / 6.9 / - / -						5.6 / 3.7 / 0.30				3.5 / 3.7 / 0.22[e]					3.5 / 3.7 / 0.02[e]		
75≤hp<100	-			- / 6.9 / - / -						5.6 / 3.7 / 0.30				3.5 / 3.7 / 0.30				0.14 / 2.5 / 3.7 / 0.015[f]			0.14 / 0.30 / 3.7 / 0.015
100≤hp<175	-		- / 6.9 / - / -						4.9 / 3.7 / 0.22				3.0 / 3.7 / 0.22					0.14 / 2.5 / 3.7 / 0.015[f]			0.14 / 0.30 / 3.7 / 0.015
175≤hp<300	-	1.0 / 6.9 / 8.5 / 0.40							4.9 / 2.6 / 0.15			3.0 / 2.6 / 0.15[g]					0.14 / 1.5 / 2.6 / 0.015[f]			0.14 / 0.30 / 2.2 / 0.015	
300≤hp<600	-	1.0 / 6.9 / 8.5 / 0.40					4.8 / 2.6 / 0.15					3.0 / 2.6 / 0.15[g]					0.14 / 1.5 / 2.6 / 0.015[f]			0.14 / 0.30 / 2.2 / 0.015	
600≤hp≤750	-	1.0 / 6.9 / 8.5 / 0.40						4.8 / 2.6 / 0.15				3.0 / 2.6 / 0.15[g]					0.14 / 1.5 / 2.6 / 0.015[f]			0.14 / 0.30 / 2.2 / 0.015	
Mobile Machines > 750hp	-					1.0 / 6.9 / 8.5 / 0.40						4.8 / 2.6 / 0.15					0.30 / 2.6 / 2.6 / 0.07				0.14 / 2.6 / 2.6 / 0.03
750hp<GEN ≤1200hp	-					1.0 / 6.9 / 8.5 / 0.40						4.8 / 2.6 / 0.15					0.30 / 2.6 / 2.6 / 0.07				0.14 / 0.50 / 2.6 / 0.02
GEN>1200 hp	-					1.0 / 6.9 / 8.5 / 0.40						4.8 / 2.6 / 0.15					0.30 / 0.50 / 2.6 / 0.07				0.14 / 0.50 / 2.6 / 0.02

Source: derived from California Air Resources Board, http://www.arb.ca.gov/msprog/ordiesel/documents/Off-Road_Diesel_Stds.xls.

a) When ARB and USEPA standards differ, the standards shown here represent the more stringent of the two.
b) Standards given for all sizes of Tier 1 engines are hydrocarbons/oxides of nitrogen (NOx)/carbon monoxide (CO)/particulate matter (PM) in grams per brakehorsepower per hour (g/bhp-hr).
c) Standards given for all sizes of Tier 2 and Tier 3 engines, and Tier 4 engines below 75 horsepower are non-methane hydrocarbons (NMHC)+NOx/CO/PM in g/bhp-hr.
d) Standards given for Tier 4 engines above 75 horsepower are NMHC/NOx/CO/PM in g/bhp-hr.
e) Engine families in this power category may alternately meet Tier 3 PM standards (0.30 g/bhp-hr) from 2008-2011 in exchange for introducing final PM standards in 2012.
f) The implementation schedule shown is the three-year alternate NOx approach. Other schedules are available.
g) Certain manufacturers have agreed to comply with these standards by 2005.

Tier 0 | Tier 1[b] | Tier 2[c] | Tier 3[c] | Tier 4 Interim/Final[c,d]

Figure 4: 2014 Statewide All Fleet Sizes (Pieces of Equipment)



Total Pieces of Equipment: 161,420

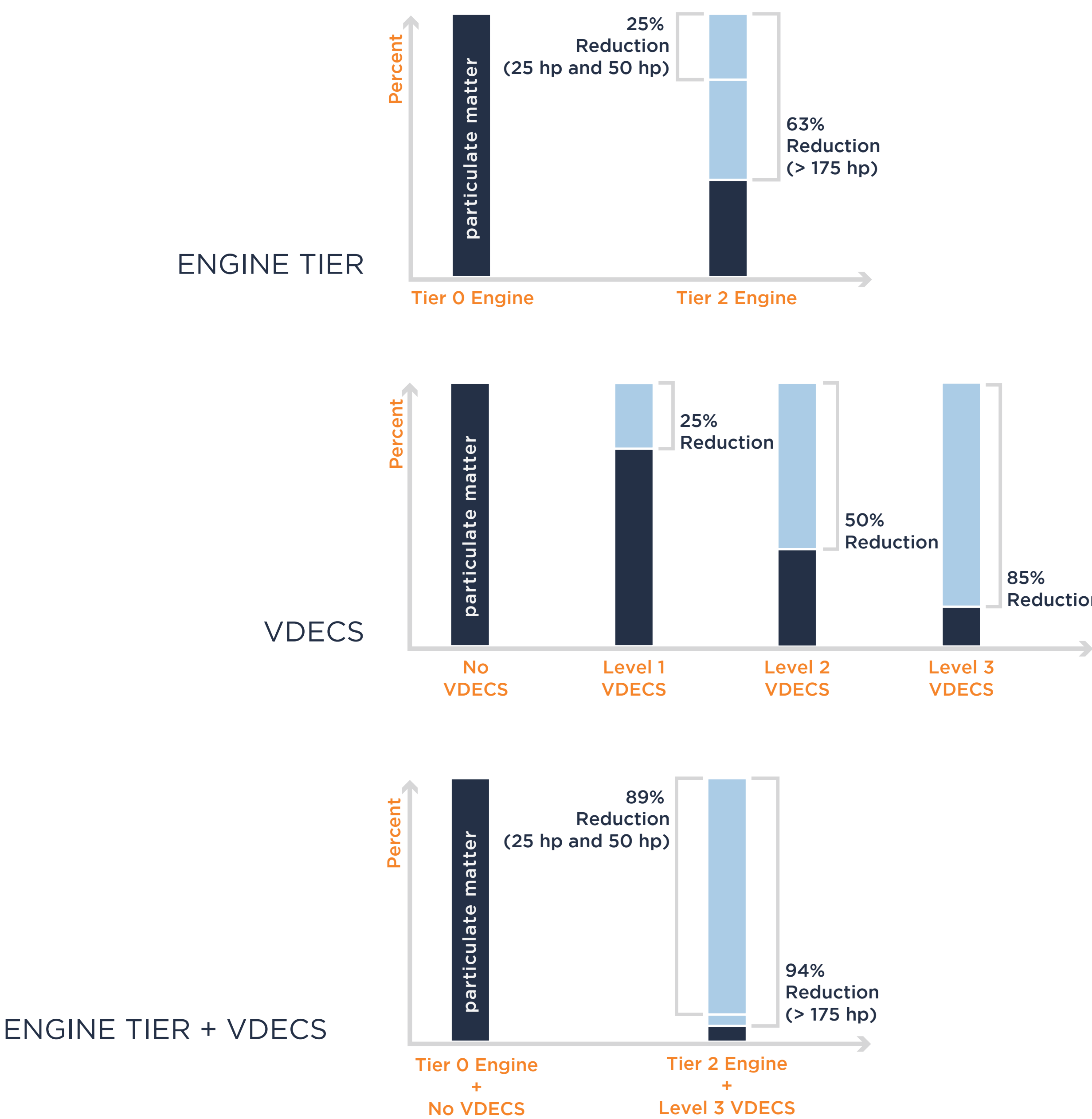
Key:
XX,XXX = Total pieces of equipment in that tier
XX% = Percent of total pieces of equipment in that tier

Particulate Matter Reduction and Health Benefits

An engine is required at a minimum to meet Tier 2 emission standards. This is required for all City projects regardless of location. This will result in between a 25 percent (25 hp and 50 hp) and 63 percent (greater than 175 hp) reduction in particulate matter emissions. Compared to Tier 1 standards, Tier 2 (and above) standards help to reduce emissions and contribute to cleaner air and a healthy community.

Level 3 VDECS, which are required for City projects in the APEZ, will result in an additional 85 percent reduction in particulate matter emissions. Therefore, requiring a Tier 2 engine with a Level 3 VDECS will result in between an 89 percent (25 hp and 50 hp) and 94 percent (greater than 175 hp) reduction in particulate matter emissions. Reduced particulate matter improves air quality and reduces the health effects associated with air pollutants.

Figure 5: Engine and VDECS Particulate Matter Reduction



How does the Clean Construction Ordinance Apply to My Project?

= Contractor

= Department Head

Is the project a major construction project* within 1,000 feet of sensitive uses**?

N → Not subject to the Clean Construction Ordinance

Y ↓

Is the project located in the Air Pollutant Exposure Zone?

(See page 3)

N → Utilize only off-road equipment and off-road engines fueled by biodiesel fuel grade B20 and utilize only off-road equipment that either:

a) Meets or exceeds Tier 2 standards for off-road engines; **or**

b) Operates with the most effective VDECS.

→ Department Head ensures that requirements included in the contract specifications

Y ↓

Prepare Construction Emissions Minimization Plan (Emissions Plan) documenting how Clean Construction Ordinance requirements (see page 2) will be met, in particular:

a) Meets or exceeds Tier 2 standards for off-road engines; **and**

b) Operates with the most effective VDECS.

(Tier 4 engines automatically meet this requirement)

Plan Components to include:

1. Equipment Inventory (See page 9-10)
2. Signage (See page 11)
3. Certification Statement (See page 12)

If applicable, Contractor seeks waivers for engine requirements

Department Head denies waiver

Department Head approves waiver

Department Head*** reviews Emissions Plan requirements and ensures Emissions Plan components included in contract specifications and signage is appropriate

Construction starts and Contractor implements Emissions Plan

Department Head responsible for ensuring that all Clean Construction Ordinance requirements are met by Contractor

Contractor prepares quarterly reports documenting compliance with the Emissions Plan and maintains at the project site

Construction completed and Contractor submits Final Report summarizing construction activities to Department Head

If applicable, San Francisco Department of Building Inspection (SFDBI) issues final certificate of occupancy

***Major Construction Project:** Public work to be performed within the geographic limits of the City that uses *off-road equipment* and that is estimated to require 20 or more cumulative days of work, including non-consecutive days, to complete.

off-road equipment: equipment with an off-road engine having greater than 25 horsepower and operating for more than 20 total hours over the entire duration of Construction Activities

****Sensitive Use:** A hospital, medical facility, school, or residence.

*****Department Head:** General manager, director, or executive director of a City Department authorized to perform public works, or that person's designee.

Construction Emissions Minimization Plan - Equipment Inventory Template

Example Inventory Equipment List*

* This sheet is partially based on the Sacramento Air Quality Management District Model Equipment List, January 20'

Submittal Date (mm-dd-yyyy):	
Contractor (Company):	
Primary Contractor (Yes or No):	
Mailing Address:	
Equipment List Contact Person:	
Phone #:	

Project Name:	
Projected Start Up Date:	
Estimated days equipment will be used on the project (start to finish, not contract days):	
Project Location (address or extension of street work):	
On-site Contact Person:	
Phone #:	

Construction Emissions Minimization Plan Notes:

The Construction Emissions Minimization Plan (CEMP) applies to all off-road equipment >25 horsepower and working 20 hours or mo**over the entire duration of construction activities.**

Complete this equipment inventory list, which is a component of the CEMP, prior to starting construction, quarterly during construction activities, and a final report within six month of the completion of construction activities.

Include all subcontractor and rental equipment on this list or on a separate sheet if preferred.

Other components of the CEMP (i.e., idling restrictions, prohibition of portable diesel engines, maintenance and tuning, signs) shall be detailed separately and submitted for approval prior to starting construction (see example certification statement and signage).

All CEMP components shall be submitted the Department Head or designee for review and approval prior to starting construction.

See Figure 6 on Page 10

CONTRACTOR NAME	CONSTRUCTION PHASE[a]	EQUIPMENT LIST																ESTIMATES - FOR FIRST SUBMISSION OF CEMP				ACTUALS - USE FOR QUARTERLY REPORTING					
										Verified Diesel Emission Control Strategy (if applicable)								Alternative Fuel (if applicable)		Other Fuels		Quarterly (Insert Quarter of Reporting)				Cumulative Totals (To-Date)	
		Exception Seeking (if applicable)[a]	Equipment Type[a]	Equipment Manufacturer	Equipment Identification Number[a]	Engine Model Year	Engine Certification (Tier Rating)	Horsepower	Engine Serial Number	Technology Type	Serial Number	Make	Model	Manufacturer	ARB Verification Number Level	Installation Date	Hour Meter Reading on Installation Date	Type	Estimated Fuel Usage[b]	Fuel Usage (separate from Alternative Fuels)[b]	Total Hours of Operation[c]	Alternative Fuels Type	Alternative Fuel Usage[b]	Fuel Usage (separate from Alternative Fuels)[b]	Total Hours of Operations[c]	Total Hours of Fuel Usage[b]	Total Hours of Operation[c]

a. See "Notes" tab for further information

b. Provide to the nearest 10 units

c. Note: in order for a piece of off-road equipment to be exempt from the requirements of the CEMP, the piece of equipment must either be less than 25 hp or operate less than 20 hours over the entire duration of construction activities (i.e., you can not separate the hours by phase to be exempt).

Figure 6: Snapshot of Equipment Inventory Template

CONSTRUCTION PHASE[a]	EQUIPMENT LIST														
	Exception Seeking (if applicable)[a]	Equipment Type[a]	Equipment Manufacturer	Equipment Identification Number[a]	Engine Model Year	Engine Certification (Tier Rating)	Horsepower	Engine Serial Number	Verified Diesel Emission Control Strategy (if applicable)						
									Technology Type	Serial Number	Make	Model	Manufacturer	ARB Verification Number Level	Insta... D...
1	2	3		4		5								6	

1

CONSTRUCTION PHASES:
- Demolition
- Site Preparation
- Grading
- Building Construction
- Architectural Coatings
- Paving
- Other__________

2

EXCEPTION SEEKING (if applicable):
- Technically Infeasible
- Not Effective
- Hazard
- Emergency

3

EQUIPMENT TYPE:
- Bore/Drill Rigs
- Cranes
- Crawler Tractors
- Excavators
- Graders
- Off-Highway Tractors
- Off-Highway Trucks
- Pavers
- Paving Equipment
- Rollers
- Rough Terrain
- Forklifts
- Rubber Tired Dozers
- Rubber Tired
- Loaders
- Scrapers
- Skid Steer Loaders
- Surfacing Equipment
- Tractors/Loaders/
- Backhoes
- Trenchers
- Other Equipment

4

5

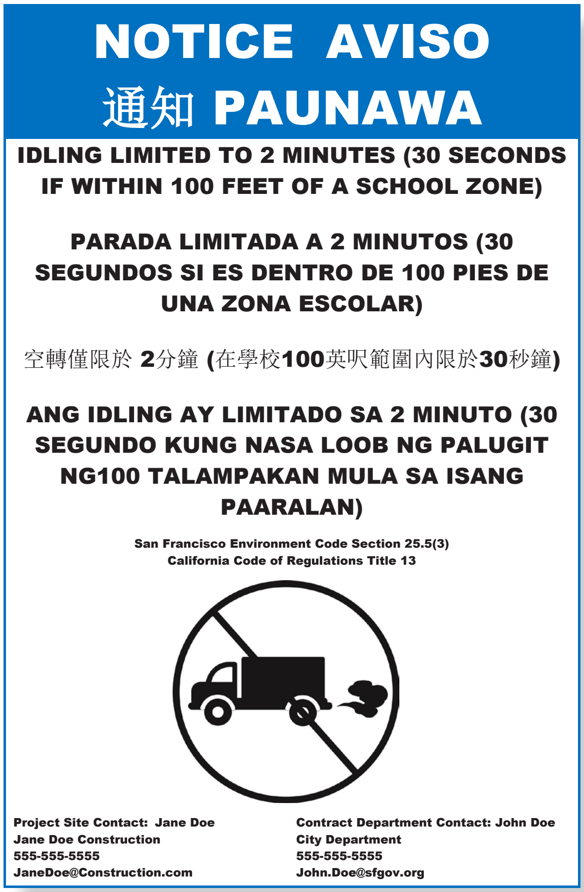
ENGINE CERTIFICATION (TIER RATING):
- Tier 2
- Tier 3
- Tier 4 Interim
- Tier 4 Final

6

ARB VERIFICATION NUMBER LEVEL:
- Level 1
- Level 2
- Level 3

Construction Emissions Minimization Plan - Signage

Figure 7: Idling Restriction Sign Template



Idling:

A legible and visible idling sign shall be posted in English, Spanish, and Chinese in designated queuing areas and at the construction site to remind operators of the idling limit.

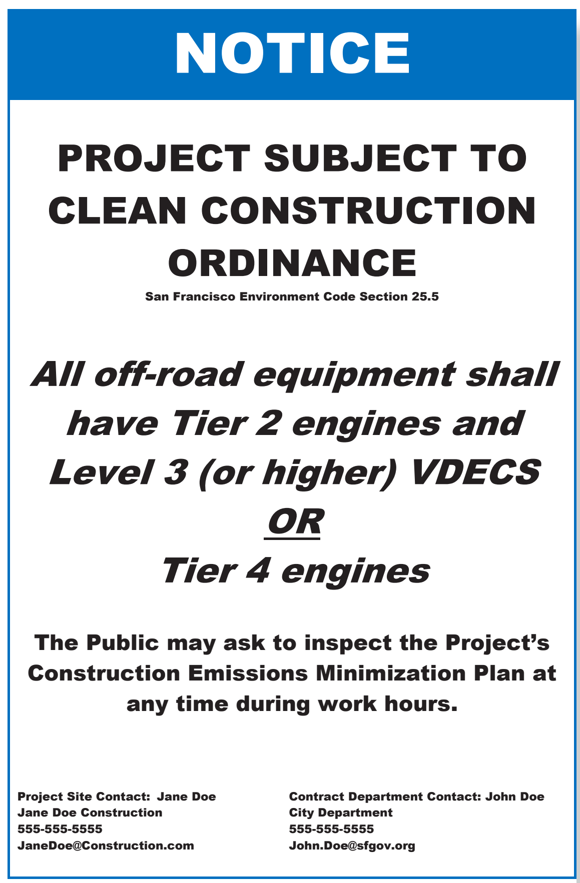
Recommended Size: 11”x17”

Clean Construction Requirements:

The Contractor shall post at the construction site a legible and visible sign summarizing the Construction Emissions Plan and shall explain how to request to inspect the Emissions Plan. The Contractor shall post at least one copy of the sign in a visible location on each side of the construction site facing a public right-of-way.

Recommended Size: 11”x17”

Figure 8: Clean Construction Requirements Sign Template



Construction Emissions Minimization Plan - Certification Statement Template

Contract Specifications and Certification Statement

The Department Head shall ensure that all applicable requirements of the Construction Emissions Minimization Plan have been incorporated into the contract specifications. The contract shall include a statement (Certification Statement) that the Contractor agrees to comply fully with the Emissions Plan and acknowledges that a significant violation of the Emissions Plan shall constitute a material breach of contract.

Figure 9: Certification Statement Template

Emissions Plan Certification Statement

I hereby certify that:

1. The off-road equipment identified in the Emissions Plan meets the engine standards in the Clean Construction Ordinance (Chapter 25 of the Environment Code).
2. All of the requirements in the Plan will be followed and will be incorporated into the contract specifications.
3. A significant violation of the Emissions Plan shall constitute a material breach of the contract. Any discrepancy to the Clean Construction Ordinance requirements will be reported to the Department Head immediately.

I understand that the construction site is subject to random and scheduled inspection to verify the requirements of the Emissions Plan.

I certify to the best of my knowledge that I will comply with the items listed above and that I am legally authorized signatory or designee for the Applicant.

Signature	Title
Print Name	Date
Company Name	Phone Number
Company Address	

Resources

Templates and Handouts

Download Templates, including:

- Equipment Inventory Template (as discussed on Page 9-10)
- Signs (as discussed on Page 11)
- Certification Template (as discussed on Page 12)
- Notice of Clean Construction Requirements Handout Template (See Page 14)

Visit: https://www.sfdph.org/dph/EH/Air/default.asp

Incentive Programs

The Carl Moyer Air Quality Standards Attainment Program provides monetary grants to private companies and public agencies to clean up their heavy-duty engines/equipment. Carl Moyer Program is administered locally by the Bay Air Area Quality Management District (BAAQMD). The Carl Moyer Program provides incentives to cover the incremental cost of purchasing engines and equipment that are cleaner than required by law. Eligible projects include off-road vehicle engine repowers, retrofits and equipment replacements; on-road truck replacements or retrofits; marine and locomotive engine replacements; light-duty vehicle scrap programs; and, agricultural engine replacements and retrofits. The Program provides funds for significant near-term reductions in nitrogen oxide emissions, reactive organic gases, and particulate matter emissions.

For more information regarding the Carl Moyer Program: www.baaqmd.gov/moyer

Technical Assistance to Local Businesses

The San Francisco Department of the Environment will provide technical assistance to businesses verified as Local Business Enterprises (LBEs) by the Human Rights Commission, and other local businesses in securing available local, State, and Federal public incentive funding to retrofit, repower, or replace off-road equipment or off-road engines operated by such businesses within the City.

Fact Sheets and More Information

The City of San Francisco wants to help improve air quality through cleaner construction equipment. For more information, please see the following resources:

California Air Resources Board (ARB)

- Knowledge Center for the Off-Road Diesel Vehicle Regulation: http://www.arb.ca.gov/msprog/ordiesel/knowcenter.htm
- Summary of Verified Diesel Emission Control Strategies: http://www.arb.ca.gov/diesel/verdev/vt/cvt.htm
- Retrofit Device Verification Database (Landing Page): http://www.arb.ca.gov/diesel/verdev/vdb/vdb.php

Environmental Protection Agency (EPA)

- Diesel Particulate Filter General Information Technical Bulletin (May 2010): http://www.epa.gov/cleandiesel/documents/420f10029.pdf
- Diesel Particulate Filter Installation Technical Bulletin (May 2010): http://www.epa.gov/cleandiesel/documents/420f10028.pdf
- Diesel Particulate Filter Operation and Maintenance Technical Bulletin (May 2010): http://www.epa.gov/cleandiesel/documents/420f10027.pdf

Other

- Clean Diesel ClearingHouse: http://tool.cleandieselclearinghouse.org

Figure 10: Notice of Clean Construction Requirements Handout Template

Notice of Clean Construction Ordinance Requirements for Publicly-Funded Projects

This is a publicly-funded major construction project located in the City of San Francisco; therefore, it is required to conform to the Clean Construction Ordinance (San Francisco Environment Code Section 25.5).

Projects **located** in the Air Pollutant Exposure Zone must comply with the following requirements:

Equipment Requirements:

- ☐ Use Tier 2 or higher engines **and** the most effective Verified Diesel Emission Control Strategies (Tier 4 engines automatically meet this requirement) for the engine type as certified by the Air Resources Board (ARB);
- ☐ Prohibit portable diesel engines where access to alternative sources of power are available;
- ☐ Restrict idling to two minutes; and
- ☐ Properly maintain and tune equipment in accordance with manufacturer specifications.

Construction Emissions Minimization Plan shall be prepared and include the following:

- ☐ An equipment inventory which shall include estimates of the construction timeline by phase with description of each piece of off-road equipment required for each phase;
- ☐ Signage indicating idling limits and engine/Verified Diesel Emission Control Strategies requirements; and
- ☐ Certification Statement.

Monitoring shall begin at the start of construction activities and include:

- ☐ Quarterly reports documenting compliance with the Emissions Plan which shall be maintained at the project site; and
- ☐ Final report summarizing construction activities.

Projects **not located** in the Air Pollutant Exposure Zone must comply with the following requirements:

Equipment Requirements:

- ☐ Utilize only off-road equipment and off-road engines fueled by biodiesel fuel grade B2O and utilize only off-road equipment that either meets or exceeds Tier 2 standards for off-road engines **or o**perates with the most effective VDECS as certified by ARB.

Documentation must be submitted to the head of the department (Department Head) authorized to perform Public Works. The Department Head will be contacted by the inspector if the project is in violation of the Ordinance. Violations may be punishable by refusal to certify the award of contract; suspension of a contract, withholding of City funds; recession of contract; debarment; and any other remedy authorized in law or equity.

Thank you for your attention to this notice. Please direct any questions concerning this notice to the **[Name], [Department Name] at (415) XXX-XXXX or XXX.XXXX@sfgov.org.**

For more information, please visit https://www.sfdph.org/dph/EH/Air/default.asp

Fire at Tesla battery site in Australia raises concern over

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The largest lithium battery site was engulfed in flames with three days of efforts to extinguish the fire.

A fire that broke out at **the largest Tesla battery** installation in the southern hemisphere at the Victorian Big Battery site near Geelong has raised fresh concern about the risk of using lithium batteries to store renewable energy (https://www.technowize.com/tesla-solarcity-empowered-entire-island-solar-energy/) for electricity grids.

A 13-tonne lithium battery was engulfed in flames, which then spread to an adjacent battery bank, and it took three days to extinguish the blaze.

Lithium-ion batteries can be a stop-gap arrangement

The **"Victorian Big Battery"** project using the Tesla Megapack (https://www.technowize.com/apple-to-use-tesla-megapack-batteries-at-its-solar-park-for-storage/) is the largest in the country, with 210 packs capable of storing up to 450 megawatt-hours of energy for the electricity grid. The Geelong site is owned and operated by the French renewable energy developer Neoen. The company says the 450 megawatt-hour battery has enough energy to power half a million homes for one hour, but its main role is to feed power into the grid when it's unstable in order to stop blackouts. It was scheduled to begin operating in November this year.

Fire at Tesla battery site in Australia raises concern over lithium risk (https://www.technowize.co at-tesla-battery-site-in-australia-raises-concern-over-lithium-risk/)
0
19

Apple Car to come with lighted display for indicators (https://www.technowize.co car-to-come-with-lighted-display-for-indicators/)
0
41

— Battery industry is more worried about the lithium risks now.

Neoen said it was too soon to tell how the commission would be affected, and testing would resume only once safety conditions were met. Renewable energy wants attention for the lithium ion-batteries.

Utilities around the world are turning to large lithium-ion batteries (https://www.industryleadersmagazine.com/tesla-rivals-close-to-commercializing-new-lithium-ion-battery-technology/) to store renewable energy from the wind and the sun. According to consultancy Wood Mackenzie, the amount of energy storage deployed last year rose 62 percent, and the market is set to grow 27-fold by the end of the decade.

Lithium batteries (https://www.industryleadersmagazine.com/innovative-pomegranate-inspired-design-solves-major-drawbacks-for-lithium-ion-batteries/) are seen as a stable power source in times of need and extreme weather. However, the technology is far from perfect as it can be a stop-gap arrangement only and can produce a limited amount of electricity.

Lithium-ion batteries catch fire from overcharging due to a "thermal runaway." Heat, as well as a mixture of gases, are produced, which, when released form a vapor cloud that can ignite or cause an explosion. There have been **38 large lithium ion battery fires** since 2018, according to Paul Christensen, a professor at Newcastle University. In Beijing, a fire at a lithium-ion battery installation in April killed two firefighters, and more than 200 firefighters were deployed to bring under control. Last September, a large lithium-ion battery in Liverpool, owned by Danish renewable energy company Orsted, caught fire.

Experts are worried about the difficulty in controlling such fires. The fire is highly explosive and hazardous because of the release of gases. "We don't have a definitive answer of what is the best way to deal with an EV [electric vehicle] fire (https://www.industryleadersmagazine.com/tesla-model-s-cars-could-put-you-on-fire-literally/) or energy storage fire," Christensen said. "They [lithium-ion batteries] are essential to the decarburization of this planet but their penetration into society has far outstripped our actual knowledge of the risks and hazards associated with them," he said.

What is worrisome is the risk involved when individual households increasingly install lithium-ion batteries to store energy from solar panels (https://www.industryleadersmagazine.com/antisolar-panels-used-to-harvest-energy-after-sundown/) to reduce reliance on electricity grids.

Matt Deadman, lead officer for alternative fuels and energy systems at the National Fire Chiefs Council in the UK, said lithium-ion battery fires burn for much longer than usual fires and water only reduces their spread. "It's about cooling the batteries and you can extinguish the flame but lithium-ion batteries will produce their own oxygen as they break down — they will keep catching fire again, we just take as much as heat as we can out of them," he said.

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Palantir invests $25 million in EV company Faraday Future (https://www.technowize.c invests-25-million-in-ev-company-faraday-future/)
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"At the moment we rely on tried and tested firefighting methods using water which is effective but it's not a golden bullet for solving these things as quickly as you possibly can," Deadman said.

Tesla's (https://www.industryleadersmagazine.com/teslas-to-use-cobalt-free-lithium-batteries-in-new-vehicles/) revenue from the sales of its megabuck batteries has more than doubled in the latest quarter. It raked in $801 million. Elon Musk Tesla chief, said safer variants of lithium-ion technology such as lithium-iron phosphate batteries — which use iron and phosphate instead of the metals nickel and cobalt — are suitable for its large battery installations.

Lithium is highly reactive; it reacts to stimuli and is difficult to control. Influences such as high environmental temperatures, too high charging voltage, short circuit, or even too much of a heavy strain can cause an exothermic reaction in the battery.

Gavin Harper, a research fellow at the University of Birmingham, said: "It is essential that we don't stifle new innovation as it is imperative that we decarbonize rapidly, but at the same time, we need to take a precautionary approach as we deploy new technologies at scale."

Researchers at Monash University School of Chemistry and Australian company Calix have come up with a novel lithium salt that could replace the more hazardous hexafluorophosphate salt used in the battery. They have tested the novel lithium salt for high-voltage lithium batteries in electric vehicles and grid-scale storage systems and claim the salt is less hazardous than conventional battery materials.

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Victoria

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Tesla big battery fire in Victoria under control after burning more than three days

Australian Associated Press

Mon 2 Aug 2021 05.07 EDT

A large blaze at Victoria's "big battery" project has been brought under control by firefighters after burning for more than three days, allowing investigators to begin examining the site.

A Tesla battery bank caught fire while it was being set up in Moorabool on Friday morning, and then spread to a second battery.

The fire burned throughout the weekend and into a fourth day, before it was declared under control just after 3pm on Monday.

Fire crews will remain at the site for the next 24 hours “as a precaution in case of reignition” and will take temperature readings every two hours, the Country Fire Authority said.

Investigations into how the fire started will soon begin with multiple agencies involved, including Energy Safe Victoria, WorkSafe, police and the CFA.

The 300MW battery project is being produced by French renewable energy giant Neoen and was registered with the energy market operator on 28 July.

Neoen Australia managing director Louis de Sambucy told AAP its own “physical inspections and investigations are now underway”.

CFA incident controller Ian Beswicke said the fire had been particularly challenging due to the complex nature of the battery site.

“This is the first mega pack fire that’s ever happened in the world, is our understanding,” he said.

“They are difficult to fight because you can’t put water on the mega packs … all that does is extend the length of time that the fire burns for.”

Firefighters have taken advice from experts including Tesla, the battery’s creators, and UGL, who are installing the battery packs.

“The recommended process is you cool everything around it so the fire can’t spread and you let it burn out,” Beswicke said.

The site is slated to become the biggest battery in the southern hemisphere and forms part of a state government push to transition to renewable energy.

But the fire has sparked calls for the government to conduct its own probe into what happened before pressing forward.

“If Labor’s renewable energy solutions go up in flames even before they’re fully operational - what hope do Victorians have that this government will be able to effectively manage the renewable energy transition?" shadow energy minister Brad Rowswell said.

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A Victorian government spokeswoman said "full and comprehensive" investigation into the fire was underway by several agencies.

"This will span investigations into the basis of the fire, how it started and to ensure the site is safe as a workplace," she told said.

Neoen Australia said there were no injuries to workers and confirmed the site had been disconnected from the grid with no impact to electricity supply.

TECH

Tesla Megapack fire highlights issues to be solved for utility ‘big batteries’

PUBLISHED THU, AUG 5 2021·11:42 AM EDT UPDATED THU, AUG 5 2021·1:26 PM EDT

Lora Kolodny
@LORAKOLODNY

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KEY POINTS

- A Tesla Megapack fire at the Victorian Big Battery in Southeast Australia was brought under control Monday afternoon.

- Results of the investigation will be closely watched, and could influence the way such systems are designed and built, according to Paul Christensen, a professor of electrochemistry at Newcastle University whose research focuses on lithium

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A Tesla Megapack in Moss Landing, California

Andrew Evers | CNBC

A Tesla Megapack fire at the Victorian Big Battery in Southeast Australia was brought under control Monday afternoon, with fire crews remaining on site Tuesday to ensure damaged equipment would not reignite, according to the Country Fire Authority.

Inspections and investigations are now underway to determine what caused it.

The battery is owned and operated by renewable energy giant Neoen, and was developed along with partners including Tesla Energy and AusNet with some construction by Cimic Group's UGL. Tesla has not disclosed what types of cells it used systems are designed and built, according to Paul Christensen, a professor of electrochemistry at Newcastle University whose research focuses on lithium ion battery fires and safety.

Without speaking to the Victorian Big Battery's design specifically, Christensen said he would like to see fire and rescue teams involved early on in the design and installation of energy storage systems. "If the design is approved, and then the fire and rescue service are brought in -- that's the wrong way around," he said.

Among other things, developers of utility-scale batteries need to offer a means of monitoring the system that would allow owners, operators and fire crews to see what's going on inside the system at any time.

Christensen also said these systems should be designed to allow space for first responders to maneuver around and aim a hose. Plenty of water should available on site, with enough hydrants installed. Containers would ideally have "dead pipes" that are capped and stick out, allowing firefighters to connect a hose, then step away and flood the container to extinguish the flames from a safe distance.

At the moment, water remains the best way to suppress a fire in any lithium ion battery energy storage system, whether that's in a ship, an electric car or bus, or a giant system to store and dispatch energy at a power plant.

Researchers are exploring other suppressants and approaches, but fires burn particularly hot and repeated re-ignition is a risk with lithium ion battery cells.

Since lithium ion battery technology is relatively new, there's not enough information about how safe large energy storage systems are and where improvements can still be made, Christensen said.

kinds, in terms of the number of lithium ion batteries on the planet is still tiny,"
Christensen said. "When an electric vehicle or a big energy storage installation goes up, it's big news. This can cause a disproportionate amount of worry."

There have been around 40 known fires that have occurred within large-scale, lithium ion battery energy storage systems, according to Christensen's research. Those incidents, most of which occurred in the past three years, date back to 2012, and include four fires at three facilities in the U.S. in Arizona, Wisconsin and Illinois.

A 2019 disaster at the McMicken battery plant in Surprise, Arizona, seriously injured four emergency responders and is the most profound incident at a big battery in the U.S. to-date. Utility Arizona Public Service owns the site, and Fluence had provided that battery system.

In Beijing, two firefighters died, one more was injured and another first responder was missing after responding to a fire in a lithium-iron phosphate battery, which was connected to a rooftop solar installation at a shopping mall.

Lithium-iron phosphate batteries are currently considered to be the safest form of lithium ion battery, because the structure of the material in its cathode doesn't break down until higher temperatures compared to other types of batteries, for example, that contain nickel manganese cobalt.

The safety of large energy systems employing LFP batteries is currently being reviewed in light of recent developments.

No injuries reported

The Tesla Megapack fire in the Victorian Big Battery was safely contained with no temperature decline of the two affected battery packs" after that.

The Tesla Megapack fire first occurred within the 300 megawatt (450 megawatt hours) system in Geelong, Victoria starting Friday morning. More than 30 fire trucks and support vehicles and about 150 fire fighters from the CFA and local Fire Rescue Victoria responded, containing the flames so they only affected two Megapacks of the approximately 210 that make up the system.

Surrounding neighborhoods received toxic air alerts but the air quality had improved to healthier levels by Sunday.

Tesla, AEMO and others did not respond to requests for further information including when they expect to complete an investigation into the cause of the fire, what they suspect the cause may be, and when they will be able to rebuild, complete testing of the big battery and connect it to the power grid.

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