

CarGHG Summary

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CarGHG is a set of open-source tools that estimate and visualize vehicle greenhouse gas (GHG) and cost performance. It draws heavily on other open-source projects and data. All source code and ready-to-use programs are available at www.carghq.org.

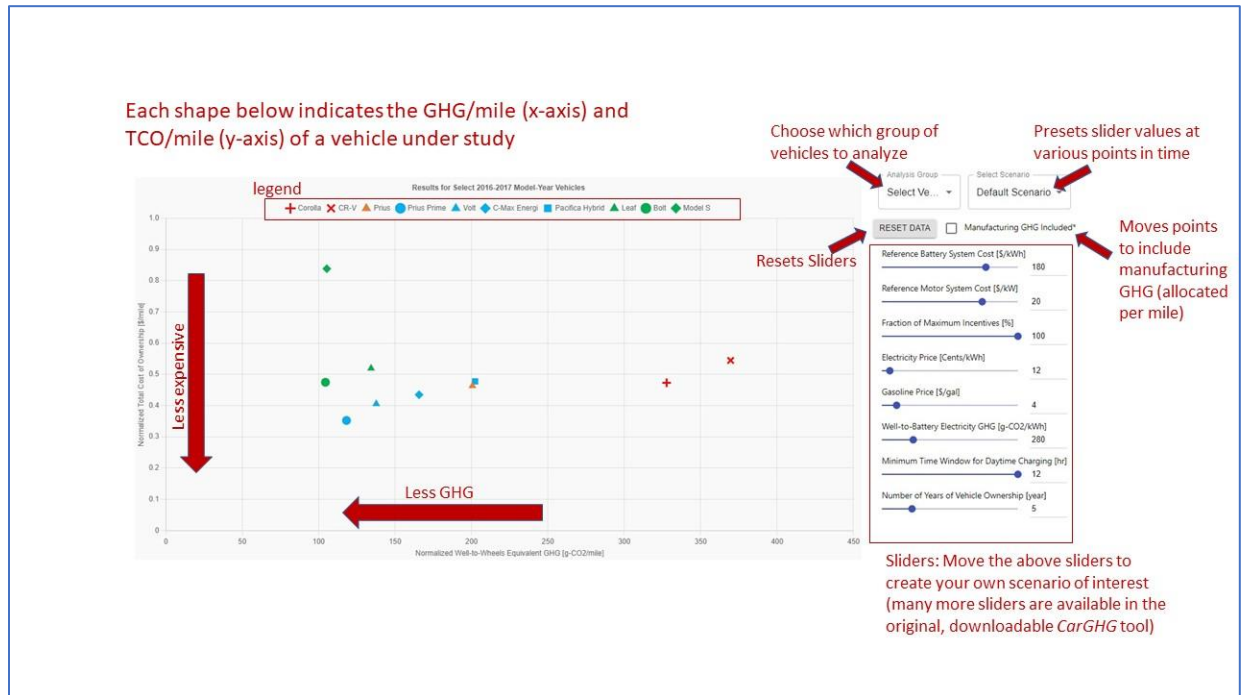


Figure 1: A screenshot of CarGHG Web, the CarGHG version available as web application. [2]

Note that red text, arrows and boxes do not appear on CarGHG Web, but are included here to identify key features of the application.

CarGHG has the following capabilities:

1. Estimate the GHG per unit-distance associated with any vehicle under study. *CarGHG* comes bundled with several models of both existing vehicles, e.g. the Chevy Bolt (with 238 mile all-electric range), as well as virtual, generic vehicles, e.g. a small SUV (Honda CRV-class) BEV with 400 mile all-electric range.
 - a. The models of existing vehicles have been validated against actual driving performance, as explained in [3-5]
 - b. Additional vehicle models can be added to *CarGHG* by users².

¹ The authors wish to recognize several colleagues that played important roles in shaping and developing *CarGHG*, including Jean Chu, John Willard, and Nicholas Makharinets.

² The developers of *CarGHG* have added several vehicle models over the years, and this process is well-understood, but not well-documented.

2. Estimate the total cost of ownership per unit-distance of acquiring, maintaining, and operating the same vehicle models under study, with each cost component separately identified.
3. *CarGHG* comes bundled with a large set of representative personal vehicle trips, collected from instrumented, on-road vehicles. *CarGHG* is further able to operate with user-supplied trip data.
4. Visualize GHG and cost performance of multiple vehicle models.
5. Users can modify several key assumptions, and the impact of different assumptions can be visualized using sliders accessible from *CarGHG*'s user interface.
6. Full functionality of *CarGHG* is available from downloading the pre-compiled application, which has been tested on Windows, MacOS, and Linux. An Android version is also available. In addition, a web application of *CarGHG*, named *CarGHG Web*, can be accessed by visiting app.carghg.org. *CarGHG Web* has a subset of the functionality of the original, downloadable *CarGHG*, but can be used without software download or installation.

A screenshot of the web application, including configurable sliders, is shown in Figure 1. Note that all red text, boxes, and arrows in Figure 1 is an overlay of the actual tool, identifying key features.

From open-source, to open-source

The core functionality of *CarGHG* comes from three open-source, peer-reviewed components:

1. GHG estimates: NREL's *FASTSim* tool [6]
2. Cost estimates: Hamza's highly-configurable vehicle cost model [7]
3. Trip data: Approximately 65000 once-per-second speed traces, collected on-road by instrumented vehicles via the *California Household Transportation Survey* (CHTS) [8], and maintained by NREL's *Transportation Secure Data Center* [9]

Note that items 1 and 3 are primarily developed and maintained by the *US Department of Energy's* (DoE) *National Renewable Energy Laboratory* (NREL) [1]

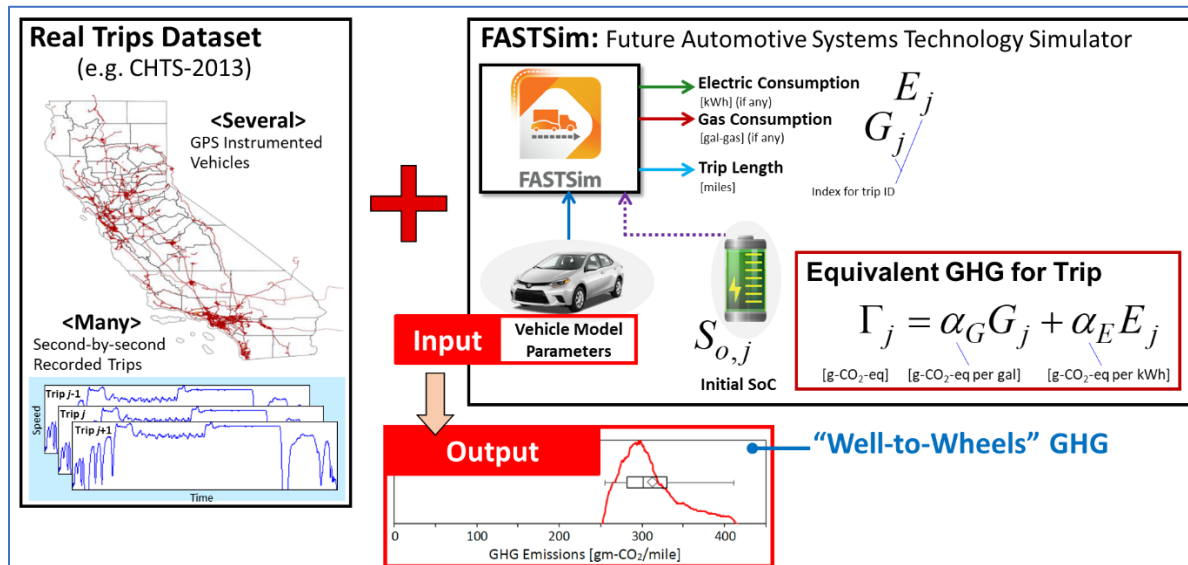


Figure 2: Framework used by CarGHG to estimate greenhouse gas performance for a vehicle under study. Reproduced from presentation for [10]

The framework that *CarGHG* uses these components to estimate GHG performance is shown graphically in Figure 2. For the first trip in the dataset, a *FASTSim* simulation is conducted, utilizing the model parameters of the vehicle under study, and the initial state of the traction battery (if any) at the start of each trip. *FASTSim* then estimates the amount of gasoline and/or electricity that the vehicle model would consume to follow the speed trace of that first trip. Multiplying the unit of gasoline and/or unit of electricity by its well-to-wheels carbon footprint determines the total GHG associated with that trip. Dividing that GHG trip estimate by the total distance of that trip gives the GHG-per-unit-distance of that first trip.

The process is repeated for every other trip in the dataset, each providing a distinct estimate of GHG-per-unit-distance of the same vehicle model. Statistical analysis of the GHG-per-unit-distance is then visualized. When using the bundled *CHTS* dataset, which we assume represents a good approximation of how Californians drive, the question answered by *CarGHG* is, “If every Californian drove the same vehicle, what would the real-world GHG performance be?”

CarGHG is an open-source tool. All code and documentation are available at www.carghg.org.

Tailpipe GHG Only

CarGHG is built to estimate well-to-wheel³ emissions. This means that all GHG released in the process of extracting, producing/processing, delivering, and using the fuel, be it gasoline or electricity, is included in the GHG per-unit-distance estimate.

However, *CarGHG* can also be used to provide reasonable estimates of tailpipe-only GHG. To accomplish this, the user could set the *Well-to-Battery Electricity GHG* to zero, and then note the resulting tailpipe-only estimates. For technical reasons, the *CarGHG* results for battery electric vehicles (BEVs) will not exactly equal zero, but a user should treat the estimate as if it is zero. For all other vehicles (with tailpipes), the *CarGHG* estimate closely approximates tailpipe-only emissions.

The Small SUV Example

To isolate the impact of the choice of powertrain on overall vehicle performance, *CarGHG* now includes a *SmallSUV* family of vehicle models. These models, similar to a Honda CRV or Toyota RAV4, all approximate the same vehicle’s body and driving performance. At the time of this writing, this vehicle class is the most popular sold in the US. By comparing these vehicle models, tradeoffs and sensitivity analyses of varying powertrains can be observed. Users have the ability to modify key scenario parameters (e.g. the cost of a unit of vehicle battery, the price of a unit of gasoline, the carbon intensity of the electrical grid, etc.).

To keep the driving and handling experience consistent across the vehicle family, all vehicles have the same power-to-weight ratio. As such, heavier powertrains will have necessary adjustments, including a modest increase in driving power, a stronger suspension, etc. The external appearance of each vehicle in this model family would be nearly identical, as would be the driving experience.

³ *CarGHG* also has the capacity for life cycle analysis (LCA) via incorporating estimate of vehicle and battery manufacturing GHG from public sources and tools such as GREET [12]. The graphical user interface allows switching between use-phase-only GHG vs LCA GHG estimates.

The process of creating these self-consistent vehicle models is described in Section 2.3 of [11].

The default settings at smallsuv.carqhg.org make the assumption that the well-to-battery GHG, i.e. the electrical grid's carbon intensity, is 220 g-CO₂e/kWh. This is roughly half of the 2022 US average (per US Electricity Grid mix from the US Energy Information Administration (EIA) [13]), and close to the present-day Californian grid. As such, the default value for grid carbon intensity represents a present-day estimate for California, as well as a likely future scenario for all the US, should the US Grid cut its carbon emissions by half. Of course, other scenarios of grid carbon intensity, including the zero-carbon case, can be generated by adjusting the *Well-to-Battery Electricity GHG* slider in the *CarGHG* user interface.

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