Program Record (Offices: Fuel Cell Technologies & Vehicle Technologies)	
Record #: 16004	**Date:** May 10, 2016
Title: Life-Cycle Greenhouse Gas Emissions and Petroleum Use for Current Cars	
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Item

Life-cycle greenhouse gas (GHG) emissions and petroleum consumption per mile were calculated for nine current technology cars (on today's market) based on a range of fuel economy for each vehicle assumed at -12%/+12% of rated fuel economy (range based on a review of www.fueleconomy.gov).

- The unhybridized gasoline and diesel vehicles (compact Honda Civic, subcompact Nissan Versa, mid-size Chevrolet Cruze) vehicles emit 310–410 g of GHGs and use 3,000–4,200 Btus of petroleum per mile, versus 300–370 g GHGs and 95–100 Btus of petroleum (life-cycle) per mile for the compact Honda CNG Civic.
- The gasoline mid-size Prius, a hybrid electric vehicle (HEV), emits 230–280 g of GHGs and uses 2,100–2,700 Btus of petroleum per mile, compared to the gasoline (compact Chevrolet Volt) extended range electric vehicle's (EREV's) 260–320 g of GHGs and 1,200–1,500 Btus of petroleum per mile.
- The (~83-mile on road) battery electric vehicles (BEVs)—mid-size Leaf and subcompact Spark—emit 200–260 g of GHGs per mile, and use 110 Btus of petroleum (life-cycle) per mile, respectively.
- The subcompact Mirai, a fuel cell electric vehicle (FCEV) on natural gas-based hydrogen, emits 230–260 g of GHGs and uses about 230 Btus of petroleum (life-cycle) per mile (with 33% renewable hydrogen, a California requirement,[1] the GHG emissions would be 190 g and petroleum use would be 180 Btu per mile, assuming manufacturing electricity is from the average U.S. grid).

The nine vehicles are already making a positive impact because their GHG/petroleum attributes compare well with the U.S. light-duty vehicle (LDV) fleet's average of approximately 430 g GHGs/mile and 3,800 Btus of petroleum/mile (Environmental Protection Agency 2014[2]).

Description

To compare estimates of life-cycle greenhouse gas emissions and petroleum consumption of advanced vehicles with existing vehicles, this record documents the assumptions and results of analyses for nine current technology cars on the road in the United States. The cars are:

1. Honda Civic (compact car) on gasoline
2. Nissan Versa (subcompact car) on gasoline
3. Chevrolet Cruze (mid-size car) on diesel
4. Honda Civic (compact car) on natural gas
5. Toyota Prius (mid-size car) on gasoline
6. Chevrolet Volt (compact car) on U.S. average grid electricity and gasoline
7. Nissan Leaf (mid-size car) on U.S. average grid electricity
8. Chevrolet Spark EV (subcompact car) on U.S. average grid electricity

[1] http://www.energy.ca.gov/releases/2014_releases/2014-05-01_hydrogen_refueling_stations_funding_awards_nr.html

[2] https://www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle shows 411 g CO_2/mile, i.e., 429 g of GHGs/mile, using the factor 1.043 for converting emissions as CO_2 to GHGs (derived from a run of the Argonne National Laboratory's GREET1 model).

9. Toyota Mirai (subcompact car) on natural gas-derived hydrogen (trucked to a retail station).

In the table that follows, results include GHG emissions and petroleum consumption associated with vehicle operation, manufacturing, and recycle and disposal (for example, petroleum energy embedded in mining, transporting, processing metals and other materials for automobile manufacturing, and in the electricity used in manufacturing plants). No credit was assumed for reusing recycled specialized materials such as precious metals, lithium compounds, or carbon fiber.

The results shown in Figures 1 and 2 are based on the following key assumptions:

Life-Cycle Analysis

- The analysis included the fuel cycle and the life-cycle effects of vehicle manufacturing and disposal/recycle, assuming no replacement for major components (e.g., fuel cell, compressed tanks, motors, batteries other than two lead acid battery replacements[3]) during the vehicle life. As a result, the credit associated with recycling materials such as battery cells' lithium or platinum group metals (PGMs) from emissions control systems (gasoline, diesel, or CNG cars) or PGMs from FCEV fuel cells is not included in this analysis's GREET2 runs. More common materials such as steel, lead, nickel, and aluminum are assumed to be from both recycling and virgin sources. The recycling assumptions may change as more is known with time. The lifetime mileage is 178,000 miles (except for the shorter range BEV 100).[4]

Gasoline

- U.S. gasoline is E10 (with 10% ethanol by volume).

Electricity

- The carbon intensity[5] of electricity from the average U.S. grid was estimated at nearly 170 g CO_2 equivalent per kBtu (580 g per kWh), based on the results from Argonne National Laboratory's (ANL's) GREET[6] model (2015 Version) for today's mix of electricity in the Energy Information Administration's Annual Energy Outlook 2015.[7] The current grid mix used in this analysis is shown below.

Table 1: Electricity Shares by Fuel in GREET1 (2015 version)

Coal	40.0%
Petroleum	0.6%
Natural Gas	26.4%
Nuclear Power	19.6%
Biomass	0.3%
Renewable Sources & Other (Non-Fossil)	13.2%
Total	*100.0%*

Non-Fossil sources are tiny and include batteries, chemicals, purchased steam, sulfur, etc.

[3] Automakers continue to use the 12-volt lead acid battery for running the lights, entertainment system, and heating/cooling system even for plug-in and fuel cell vehicles.

[4] This analysis assumed 178,000-mile vehicle lifetimes for most cars, based on the National Highway Traffic Safety Administration's information: 14,231 miles in 1st year, decreasing annually to 9,249 miles in 15th year (Table 5 in http://www-nrd.nhtsa.dot.gov/Pubs/809952.PDF). BEV100 lifetime mileage was assumed to be 125,000.

[5] Fuel carbon intensity (CI) is the amount of GHG emissions, measured on a life-cycle basis, per unit of energy of fuel delivered to the vehicle. GHG emissions are the sum of the CO_2 equivalent (CO_2e) emissions of three gases, CO_2, CH_4, and N_2O, weighted by their 100-year global warming potentials from the International Panel on Climate Control. In this document, CI is expressed in g CO_2e/kBtu.

[6] The Greenhouse Gases, Regulated Emissions and Energy Use in Transportation model. https://greet.es.anl.gov, October 2015. This model, GREET1, calculates pump-to-wheels emissions per mile associated with each LDV technology (excluding vehicle manufacturing/recycling/disposal because this can be calculated with GREET2).

[7] Energy Information Administration, Annual Energy Outlook, http://www.eia.gov/forecasts/aeo/tables_ref.cfm.

Natural Gas

- The compressed natural gas (CNG) pathway includes both conventional and shale gas (GREET1 shows that both have nearly the same carbon intensity[8]).

Hydrogen

- Hydrogen from natural gas reforming at central production facilities is trucked to fueling stations (in view of California's requirement for 33% renewable content for all hydrogen used as vehicle fuel, the results for this partial renewable scenario are also shown).

Fuel Economy

The federal fuel economy website[9] shows that aggressive driving could reduce fuel economy by up to 33% on the highway and up to 5% in city driving, and a rooftop cargo box could reduce fuel economy by up to 17% on the highway and up to 8% in city driving. Therefore, assuming a variation of -12%, +12% (well within the sum of the ranges cited) around the EPA-rated fuel economy for each car gives a range of fuel economy numbers and associated per-mile GHG emissions and petroleum use.

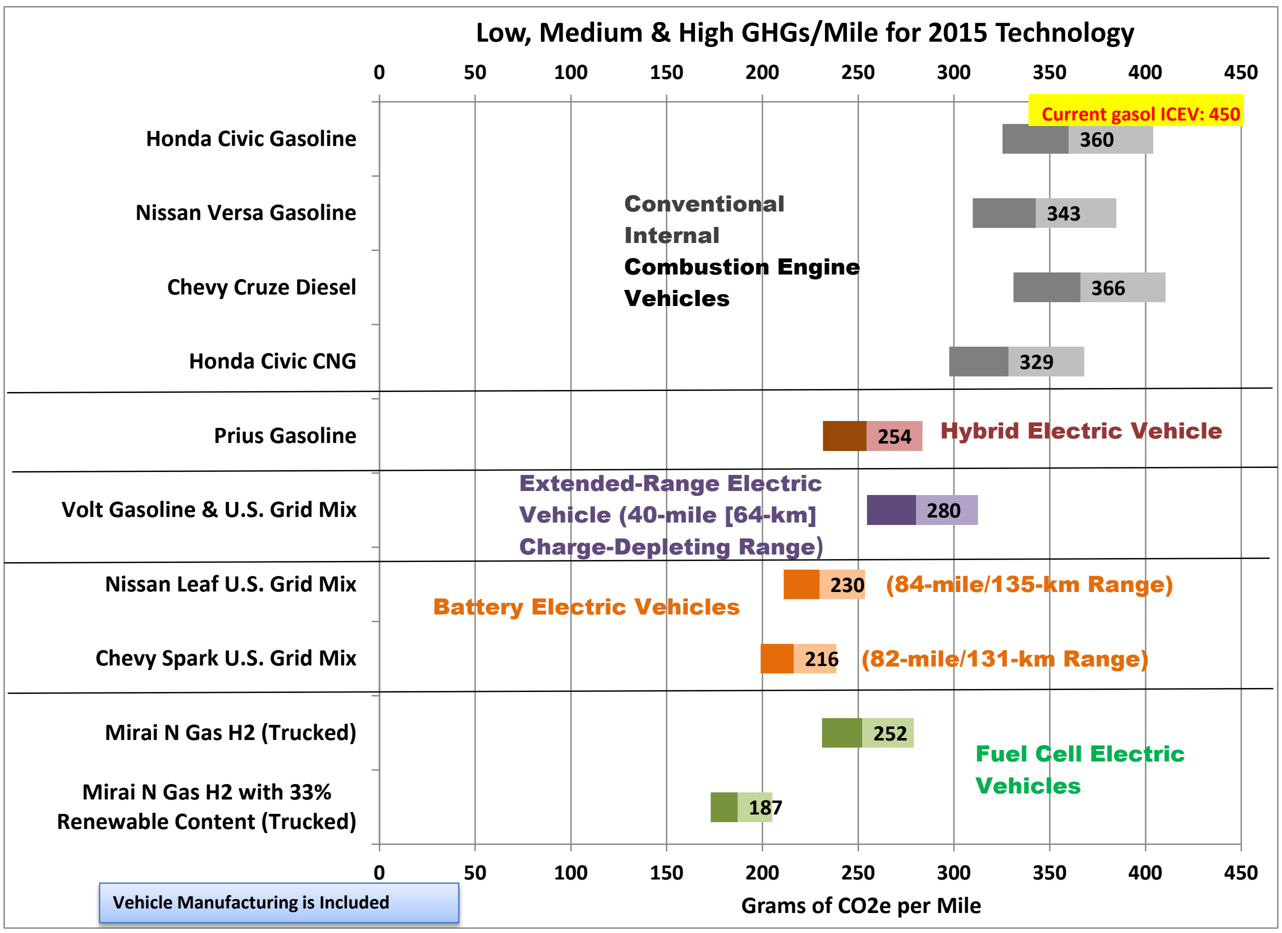

Figure 1: Greenhouse Gas Emissions, Grams CO_2 Equivalent per Mile

Range reflects -12%, +12% assumed for variation around fueleconomy.gov mileage. The range was chosen to fall within the range possibilities in https://www.fueleconomy.gov/feg/driveHabits.jsp. Fuel economy of the current mid-size gasoline internal combustion engine vehicles (ICEVs) was assumed at 26.5 mpg (within range reported at https://www.fueleconomy.gov/feg/byclass/Midsize_Cars2015.shtml), resulting in approximately 450 g CO2e/mile.

[8] From GREET1, carbon intensities of both gaseous fuels are 80.5 g GHGs per million Btus.

[9] https://www.fueleconomy.gov/feg/driveHabits.jsp.

Data, Assumptions, References

Fuel economies are from www.fueleconomy.gov.

GREET1 was used to determine the well-to-wheels (WTW) GHG emissions and petroleum energy use associated with the extraction (or growing/harvesting in the case of biofuels) of the primary fossil fuel material (coal, natural gas, crude oil, etc.) or biomass feedstock (corn or other crops), the transportation of the fuel material or feedstock to a conversion plant (or compression in the case of CNG), the production of the fuel and its transportation, distribution, delivery, and use in a vehicle. The ANL GREET2 model (2015 version) was used to calculate the petroleum energy consumption and GHG emissions associated with the production of vehicle materials, the manufacturing and assembly of the vehicle, as well as the recycling of vehicle components.

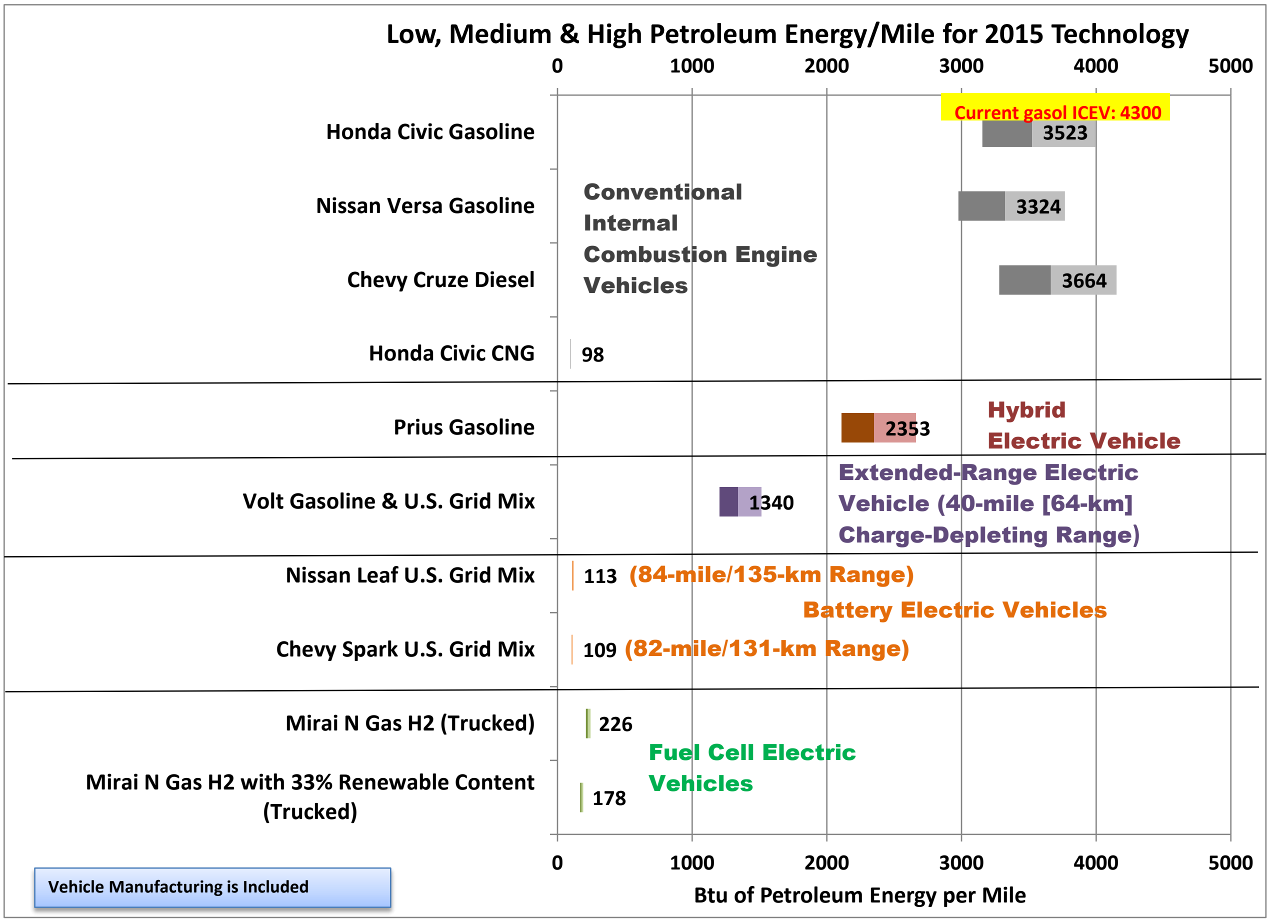

Figure 2: Petroleum Energy Use, Btus per Mile

Range reflects -12%, +12% assumed for variation around fueleconomy.gov mileage. The range was chosen to fall within the range possibilities in https://www.fueleconomy.gov/feg/driveHabits.jsp. Fuel economy of the current mid-size gasoline ICEVs was assumed at 26.5 mpg (within range reported at https://www.fueleconomy.gov/feg/byclass/Midsize_Cars2015.shtml), resulting in approximately 4300 Btu of petroleum per mile.

Table 2 lists the GHG emissions and petroleum consumption per mile and the carbon and petroleum intensities of the different fuels considered in this analysis. The right-hand column summarizes the on-road fuel economy data from fueleconomy.gov. The Manufacturing/Well-To-Wheels/Total GHG & Petroleum column includes WTW results (between brackets) found on fueleconomy.gov for comparison.

Table 2: Assumptions and Results for 2015 Technologies at Rated Fuel Economy (GHG results without vehicle manufacturing from fueleconomy.gov are shown between brackets for comparison)

Vehicle/Fuel	**Carbon Intensity of Electricity & Other Fuels (g CO2e/kBtu)**	**On-Road Fuel Economy** (miles per gge, Wh/mi) - **fueleconomy.gov**	**Life Cycle (without Manufacturing) GHG** (g CO2e/mile) & ***Petr Use*** *(Btus/mile)*	**Manufacturing GHGs** (g CO2e/mile) & ***Petr Use*** *(Btus/mile)*	**Life Cycle (with Manufacturing) GHGs** (g CO2e/mile) & ***Petr Use*** *(Btus/mile)*
Note: the above column headings apply to all vehicles in the table's subsequent rows.					
Honda Civic (compact): Gasoline (10% Ethanol)	Carbon intensity (CI) of fuel: 95	33 mpgge	GHG: **323** [330 gCO2e/mi from fueleconomy.gov.] *Petr:* ***3444***	GHG: **37** *Petr:* ***79***	GHG: **360** *Petr:* ***3523***
Nissan Versa (subcompact): Gasoline (10% Ethanol)	Carbon intensity (CI) of fuel: 95	35 mpgge	GHG: **308** [311 g] *Petr:* ***3247***	GHG: **35** *Petr:* ***77***	GHG: **343** *Petr:* ***3324***
Chevrolet Cruze midsize): Diesel	CI of fuel: 96	33 mpgge	GHG: **326** [307 g] *Petr:* ***3580***	GHG: **40** *Petr:* ***84***	GHG: **366** *Petr:* ***3664***
Honda Civic (compact): CNG	CI of fuel: 80	31 mpgge	GHG: **290** [306 g] *Petr:* ***18***	GHG: **39** *Petr:* ***80***	GHG: **329** *Petr:* ***98***
Toyota Prius (mid-size, gasoline hybrid electric)					
Gasoline	CI of fuel: 95	50 mpgge	GHG: **213** [218 g] *Petr:* ***2273***	GHG: **41** *Petr:* ***80***	GHG: **254** *Petr:* ***2353***
Chevrolet Volt (compact, gasoline extended-range electric, 38-mile charge depleting (CD) range): The share of distance travelled in the CD mode was assumed to be 60% of the total distance driven by these EREVs. EPA estimated the range on electricity at 38 miles and assumed that electricity consumption includes battery and charging losses (19% reduction in efficiency).[10]					
Gasoline & U.S. Grid electricity	Gasoline CI: 95 CI of U.S. Grid: 170	37 mpg on gasol. 350 Wh/mi on electr. (96 mpgge)	GHG: **237** [250 g] *Petr:* ***1258***	GHG: **43** *Petr:* ***82***	GHG: **280** *Petr:* ***1340***
Nissan Leaf (mid-size, battery electric, 84-mile EPA-rated range, 19% reduction in efficiency from battery and charging losses).					
U.S. Grid electricity	CI of U.S. Grid: 170	300 Wh/mile (114 mpgge)	GHG: **174** [190 g] *Petr:* ***41***	GHG: **56** *Petr:* ***72***	GHG: **230** *Petr:* ***113***
Chevrolet Spark (subcompact, battery electric, 82-mile EPA-rated range, 19% reduction in efficiency from battery and charging losses)					
U.S. Grid electricity	CI of U.S. Grid: 170	280 Wh/mile (119 mpgge)	GHG: **162** [180 g] *Petr:* ***38***	GHG: **54** *Petr:* ***71***	GHG: **216** *Petr:* ***109***
Toyota Mirai (subcompact fuel cell electric) Hydrogen from a central steam methane reforming facility. Grid electricity is used for hydrogen storage and dispensing at the fueling station.					
Trucked-in H2 from Central Nat Gas Reforming	CI of fuel: 116	66 mpgge[11]	GHG: **197** [N.A.][12] *Petr:* ***146***	GHG: **55** *Petr:* ***80***	GHG: **252** *Petr:* ***226***
As above, with 33% renewable H2 per California regulation	CI of fuel: 78	66 mpgge[13]	GHG: **132** [N.A.][14] *Petr:* ***98***	GHG: **55** *Petr:* ***80***	GHG: **187** *Petr:* ***178***

[10] http://www.fueleconomy.gov/feg/evtech.shtml.
[11] http://www.fueleconomy.gov/feg/fcv_sbs.shtml.
[12] Mirai's fuel economy is shown at www.fueleconomy.gov, but WTW results are not.
[13] http://www.fueleconomy.gov/feg/fcv_sbs.shtml.
[14] Mirai's fuel economy is shown at www.fueleconomy.gov, but WTW results are not.