To: The NJ Board of Public Utilities
Att: NJ Electric Vehicle Infrastructure - Stakeholder Group

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Reference: Comments Regarding Fossil Fuel Consumption and Companion CO_2 Emissions, When an Electric Vehicle is Charged Using the NJ Electric Grid

The amount of CO_2 emitted while transforming primary energy sources (solar, wind, NG, coal, etc.) to battery chemical energy for powering an electric vehicle's traction motor, when combined with the actual propulsion efficiency of that electric vehicle, determines the CO_2 emissions per mile traveled caused by driving that vehicle.

Consequently,

> Electric vehicles ARE zero emission vehicles, when charged using cleanly harvested solar, wind, and hydroelectric energy,
>
> while
>
> Electric vehicles ARE NOT zero emissions vehicles, when charged using NJ grid electricity.

In its recent report to the NJ BPU, the Regulatory Assistance Project (RAP)[1] emphasized the 2015 Nissan Leaf electric vehicle's ability to achieve 114 MPGe[2] fuel economy with no CO_2 emissions, in comparison to a gasoline-fueled Honda Accord having 25 MPG EPA-rating.

[1] See `http://nj.gov/bpu/pdf/reports/RAP-NJ-BPU-electricvehicles-policymemo-may2017.pdf`

[2] MPGe (Miles per gallon gasoline equivalent) is a measure of the average distance traveled per unit of energy consumed. MPGe is used by the United States Environmental Protection Agency (EPA) to compare energy consumption of alternative fuel vehicles, plug-in electric vehicles and other advanced technology vehicles with the fuel economy of conventional internal combustion vehicles expressed as miles per US gallon.

However, this comparison is incomplete as it does not account for the primary fuel consumed (and any companion CO_2 emissions that occur) in order to charge the Nissan Leaf's battery. This is the "well-to-wheel efficiency" of the battery electric vehicle, which depends upon the mix of primary energy sources used to generate the battery charge electricity.

It will be shown later in this report that NJ's present electric grid is

> 36.1% efficient,

and that if a Nissan Leaf PEV (plug-in electric vehicle)[3] is charged using an EVSE[4] battery charger powered by NJ's present electric grid, the actual "well-to-wheel" fuel economy of the Nissan Leaf is

> 41.2 MPGe,

and that

> 12.2 lbs of CO_2 emissions/GGe[5] of PEV charge electricity

will occur, at those fossil fuel power plants participating in the supply of this grid electricity.

> To accomplish zero CO_2 emission PEV travel, EVSE battery charging stations must obtain their electricity from local solar, wind, and nuclear power sources and not grid electric fossil fuel power sources.

Only then does the plug-in electric vehicle achieve both emission-free travel, and well-to-wheel fuel economy that is close to the vehicle's advertised EPA-rated fuel economy specs.

The report further examines the changing fuel economy and CO_2 emission performances of PEV vs. HEV (hybrid electric vehicles)[6] vs. traditional gasoline-fueled non-electric vehicles, assuming several U.S. electric grid evolution scenarios.

1 Discussion

Figure 1 depicts the mix of primary fuels consumed at NJ grid power plants, on average, to produce and deliver one GGe of electricity to a grid-attached EVSE for charging a Plug-In Electric Vehicle (PEV).

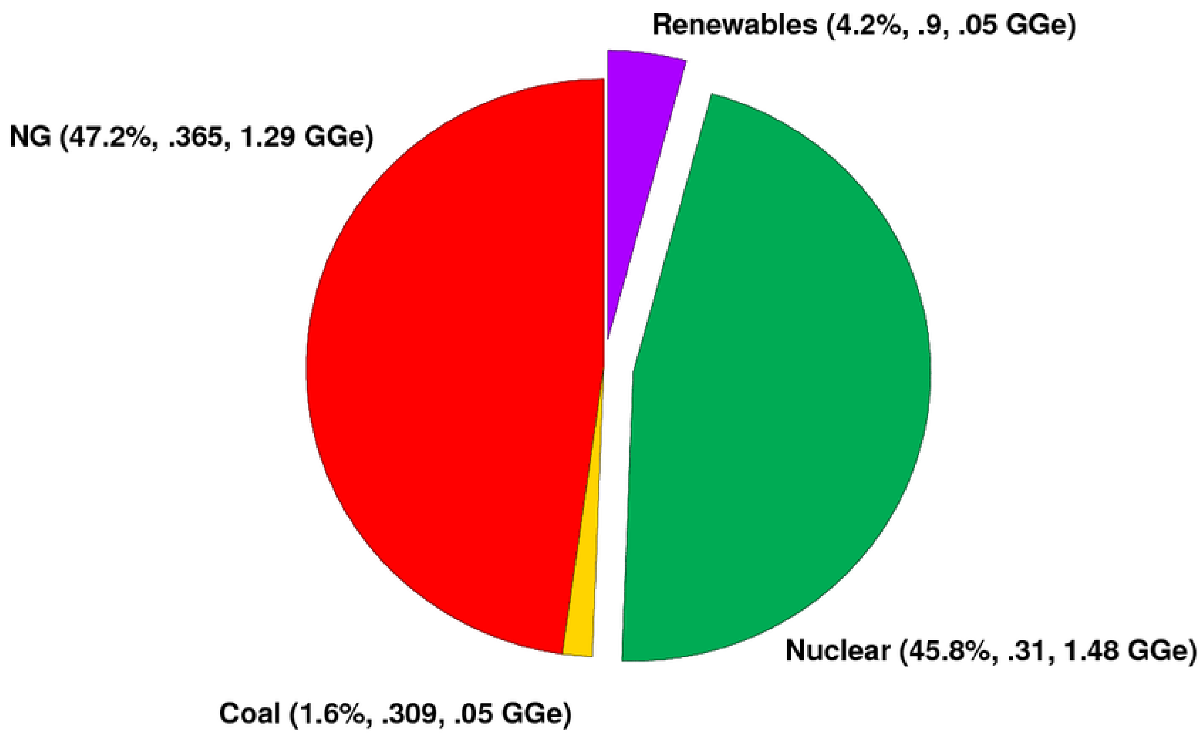
[3] A PEV is any vehicle that can be recharged from any external source of electricity, and the electricity is stored in the battery packs, to propel the Electric Vehicle.

[4] EVSE (Electric Vehicle Supply Equipment) is equipment in an infrastructure that supplies electricity for charging of electric vehicles.

[5] GGe (Gasoline gallon equivalent) is the amount of alternative fuel it takes to equal the energy content of one liquid gallon of gasoline.

[6] An HEV is a vehicle which combines an internal combustion engine (ICE) with an electric propulsion system.

Figure 1. NJ Grid Fuel Mix (May, 2017) per GGe of Delivered Electricity



The first numeric value in each fuel type label of Figure 1 indicates the percentage of each unit of delivered grid electricity that, on average, is generated by that fuel type.

CO_2 emissions occur as fossil fuel (NG and coal) power plants generate electricity, while no companion CO_2 emissions occur when nuclear, solar, or wind energy is transformed to electric electricity.

The second numeric value in each fuel type label denotes the average fuel-to-electric energy conversion efficiency of that type power plant in New Jersey, after[7] New Jersey's 5% average transmission and distribution loss is incurred.

[7]See https://www.eia.gov/electricity/state/newjersey/ and https://www.eia.gov/electricity/annual/html/epa_08_02.html

The third numeric value in each fuel type label indicates the amount of fuel consumed at power plants of that fuel type to produce its portion of the one GGe of electricity being used to charge Nissan EV's battery. For example, Figure 1 indicates that 1.29 GGe of NG and .05 GGe of coal will be burnt in fossil fuel power plants, on average, for the present NJ grid to supply one GGe of EV battery charge electricity.[8]

Table I lists the pounds of CO_2 emitted per million Btu of heat energy produced by combusting various common fuels:[9]

Table I. CO_2 Emission Intensity for Various Primary Fuels

Fuel Source	Lbs. CO_2/MM BTU
Natural Gas	117
Propane	139
Gasoline (without Ethanol)	157
Diesel fuel and heating oil	161
Coal	215

Figure 2 expresses Table I CO_2 emission intensity data in more convenient units of (Lbs. CO_2/ per GGe of heat energy) for each fuel type: [10]

[8] File "njstateprofile.pdf", provided along with this report, contains the electricity production and NG fuel consumption data as published by the U.S. Energy Information Administration (EIA) that was used to compute the average NG power plant fuel-to-electric efficiency value posted in Figure 1:

May, 2017 total NJ electric grid production = 4,908 Gw-hrs,
May, 2017 fraction generated by NG-fired power plants = .472,
May, 2017 NG consumption to produced this electricity = 20,607 million cubic feet

Each 100 cubic feet of NG at standard temperature and pressure is a therm, which contains 29.3 Kw-hrs of heat energy. Consequently,

20,607 million cubic feet of NG contains 6,030 GW-hrs of heat energy,
which was consumed to produce .472 x 4908 Gw-hrs = 2317 Gw-hrs of grid electricity.

The average efficiency of all NG power plants in NJ for May, 2017 is then

2317 Gw-hrs/6030 Gw=hrs = .384

The EIA also reports that NJ grid's transmission and distribution loss for that month was 5%. Consequently, the overall efficiency of NG-to-electric production and delivery to NJ electric grid customers was

.384 x .95 = .365

[9] See `https://www.eia.gov/tools/faqs/faq.php?id=73&t=11`

[10] Figure 2 values result from applying the energy equivalence relationships

1 Kw-hr = 3412.14 BTUs, and
1 GGe = 33.3 Kw-hrs

to Table 1 emission intensity values.

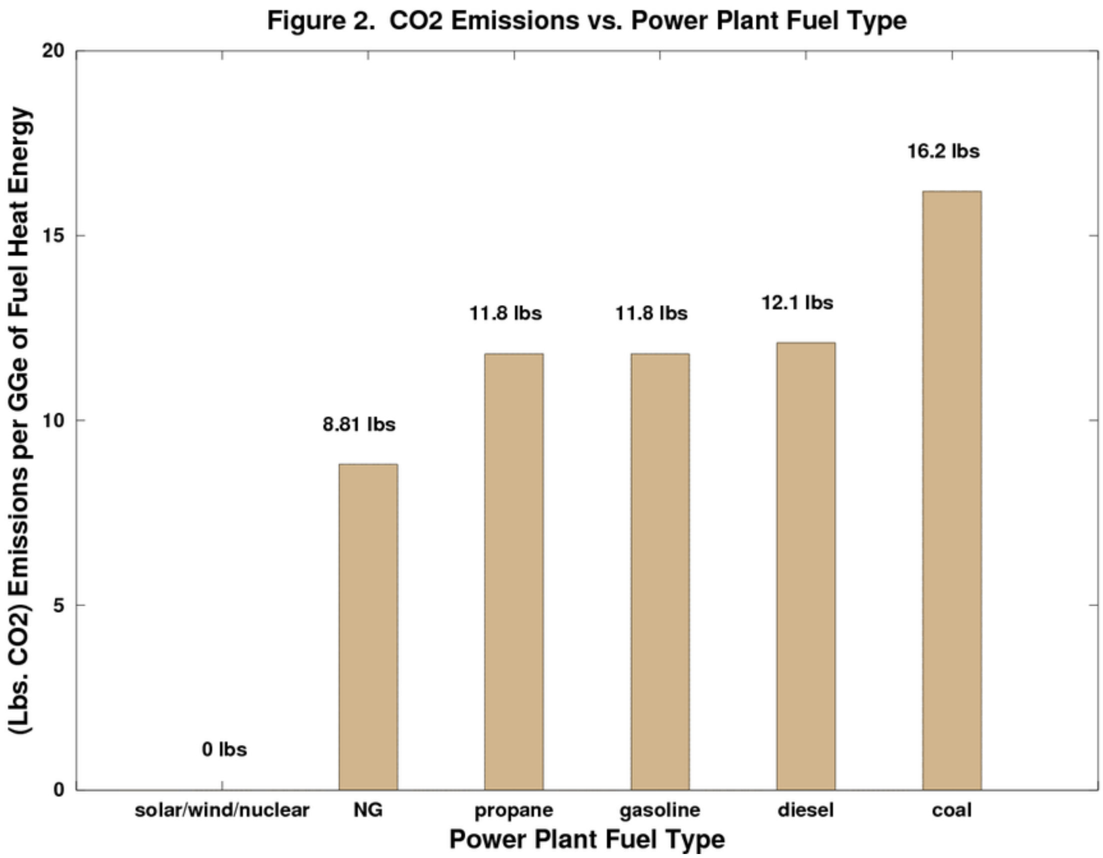


Figure 1 and 2 information were used to produce Figure 3 which shows the average number of pounds of CO_2 emitted per power plant fuel type to deliver one GGe unit of electricity over the present day NJ electric grid for charging an electric vehicle battery.

Figure 3. Source/Quantity of CO2 Emitted (per GGe Unit of NJ Grid Electricity)

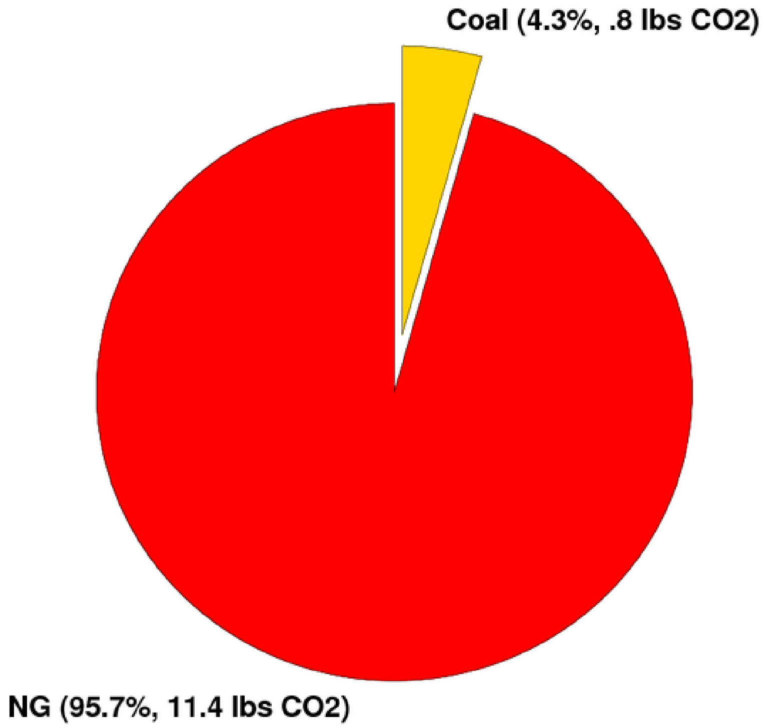


Figure 3 indicates that if NJ EVSE stations are built that rely on the present electric grid for their battery charge electricity, then

> 12.2 lbs. of CO_2/GGe of PEV battery charge

will be emitted, on average, by the NG and coal power plants that participate in the production of this needed electricity.

Alternatively,

> no CO_2/GGe of PEV battery charge

will be emitted, if instead EVSE stations normally obtain their electricity from locally-harvested solar, wind, and/or hydroelectric energy.

2 Hybrid Electric Vehicle CO_2 Emission Comparison

Many car manufacturers are offering hybrid electric vehicles (HEV)[11] featuring greater fuel economy than conventional gasoline-fueled vehicles having no electric drive train components.

This section compares the fuel economy and CO_2 emissions of the midsize 2018 Toyota Camry XLE Hybrid Vehicle[12] against that of the Nissan Leaf Plug-in Electric Vehicle when the PEV battery is grid-charged under several grid evolution scenarios.

The Toyota Camry is not a plugin electric hybrid. Rather than depending on grid electricity, the HEV charges its onboard 1.6 Kw-hr Lithium-ion battery as needed using regenerative braking power, when available, and ICE engine alternator-produced electricity, otherwise. The Toyota Camry XLE Hybrid achieves 52 MPG EPA-rated fuel economy, operating in this manner.

2.1 The Present NJ Electric Grid

Figure 2 states that one GGe of non-ethanol gasoline produces 11.8 lbs. of CO_2 when burnt to power a vehicle.

One GGe of gasoline can power 52 miles of combined city/highway travel in the Toyota Camry XLE.

A Nissan Leaf Electric vehicle charged by the present day NJ electric grid will cause

12.2 lbs CO_2 of emissions

at fossil fuel power plants that contribute to the production of one GGE of battery charge electricity (i.e., 114 miles of Nissan Leaf travel.)

Traveling the same 114 mile distance in a Toyota Camry XLE hybrid will cause (114/52)*11.8 lbs of CO_2 =

25.9 lbs of CO_2 emissions

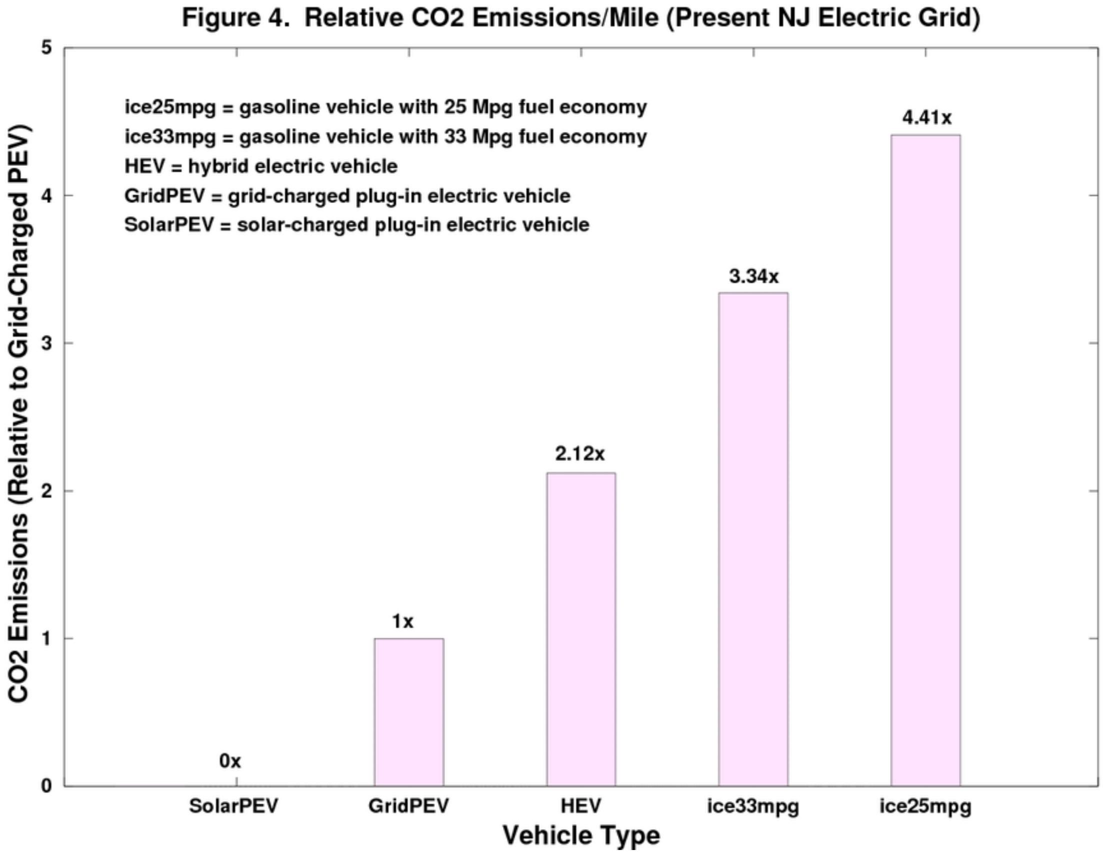
Consequently, traveling in a present day NJ grid-charged Nissan Leaf PEV causes 12.2/25.9 =

47.1%

of the CO_2 emissions that occur due to driving the same distance in a gasoline-fueled hybrid electric vehicle such as the Toyota Camry XLE Hybrid.

Figure 4 compares generated CO_2 emissions among competing vehicle technologies. For example, the HEV entry generates (1/0.471) = 2.12x the expected emissions due to traveling the same distance in a grid-charged Nissan Leaf PEV.

[11] a vehicle which combines a conventional internal combustion engine (ICE) with an electric propulsion system
[12] See https://www.caranddriver.com/reviews/2018-toyota-camry-xle-hybrid-test-review



2.2 The Electric Grid without Nuclear Power Plants

Nuclear plants are gradually being retired and often replaced with NG power plants in the United States.[13] Considering a mid-future NJ electric power grid characterized by

- 80% natural gas,
- no nuclear power plants,
- no coal power plants, and
- 20% carbon-free renewables (solar, wind, and hydroelectric),

together with Figure 2 emission intensity and Figure 1 plant efficiency data, we can estimate expected emissions to increase from 12.2 lbs. to (.8 x 8.81 lbs. x (1/.365) =

19.3 lbs of CO_2 emissions

per GGe of delivered battery charge electricity (i.e., 114 miles of Nissan Leaf travel).

[13]New Jersey has three nuclear power plants: Oyster Creek, Hope Creek, and Salem. The Oyster Creek nuclear facility is the oldest, and is scheduled to be retired no later than December 31, 2019.

It was shown in the previous subsection that to travel the same 114 miles using a Toyota Camry XLE hybrid (HEV) vehicle will cause

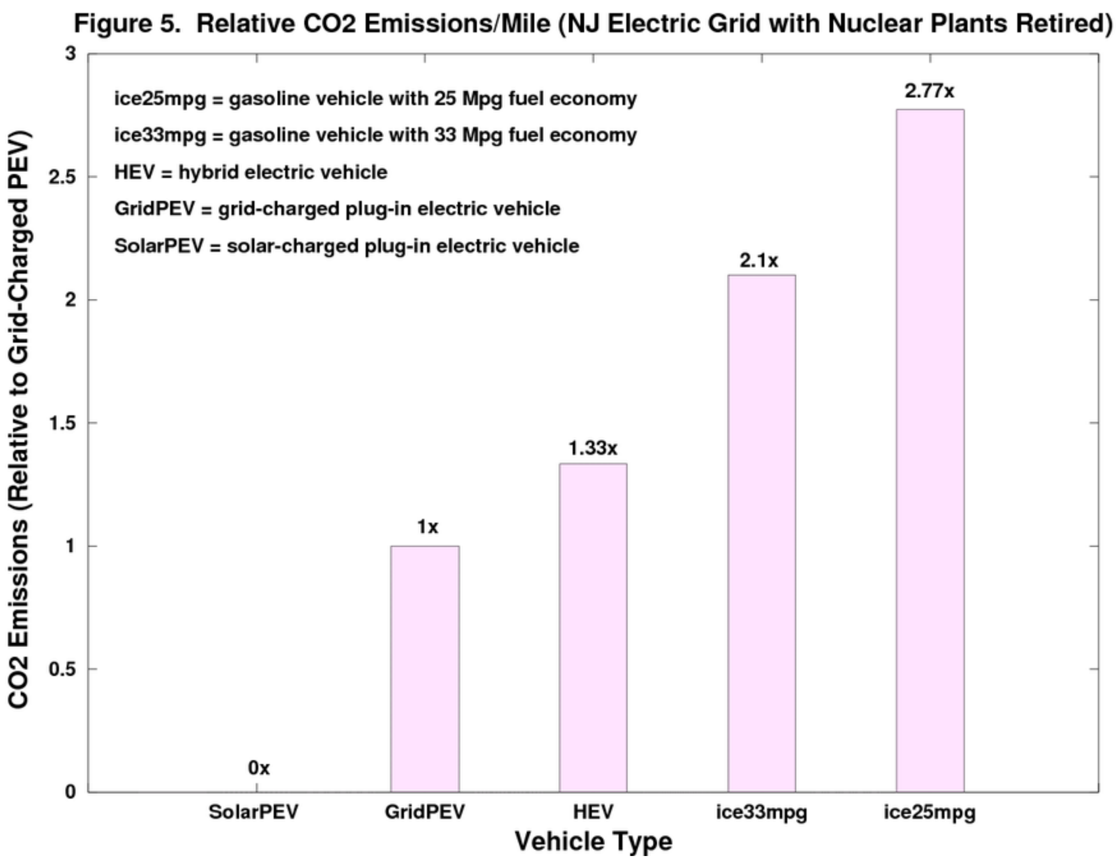
> 25.9 lbs of CO_2 emissions

Consequently, driving a Nissan Leaf PEV that is charged by an (80% NG/20% Renewables) fuel-mix NJ electric grid will cause 19.4/25.9 =

> 74.9%

of the CO_2 emissions that otherwise occur due to driving the same distance in an HEV such as the Toyota Camry XLE Hybrid.

> Under this future grid scenario, grid-charged battery vehicles are still cleaner than gasoline-fueled hybrid electric vehicles.



2.3 Worst Case: A Grid Dominated by Coal-Power Plant Electricity

Coal power plants generate the highest CO_2 emissions per GGe unit of output electricity among all common present day fossil fuel power plants.

If a Nissan Leaf battery were charged using only the electricity from today's coal power plants, the expected CO_2 emissions[14] that occur while producing one GGE of battery charge electricity is ((16.2 lbs CO_2/GGe of coal) x (1/.309) =

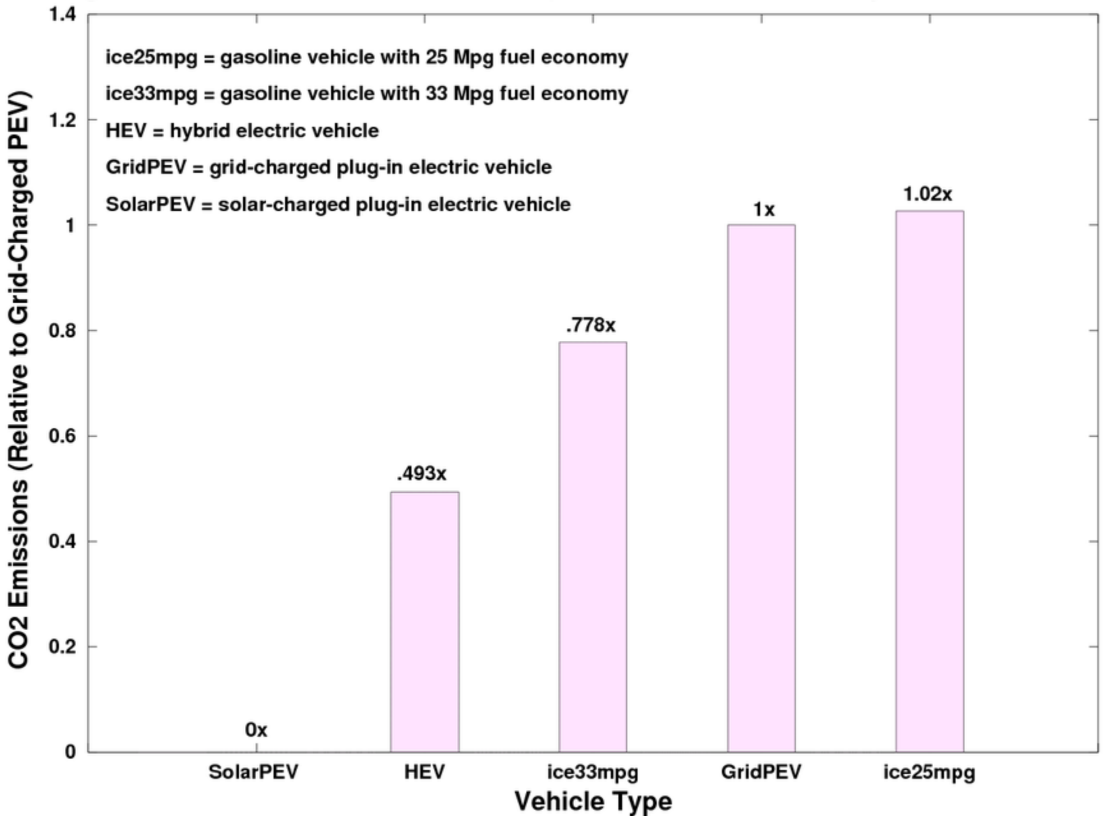
52.4 lbs. of CO_2.

Consequently, driving 114 miles in a Nissan Leaf PEV charged by coal power plant-produced electricity will cause (52.4/25.9) =

2.02x the CO_2 emissions

that otherwise occurs driving the same distance in a Toyota Camry XLE Hybrid (HEV) vehicle.

Figure 6. Relative CO2 Emissions/Mile (Electric Grid dominated by Coal Power Plants)



[14] Again, estimated using Figure 2 emission intensity and Figure 1 plant efficiency data.