PETROLEUM USE AND GREENHOUSE GAS EMISSIONS OF SELECTED ALTERNATIVE FUELS

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INTRODUCTION

The relative petroleum use and greenhouse gas (GHG) emissions for several popular and proposed alternative fuels were estimated and compared with conventional petroleum fuels, either gasoline (non-oxygenated) or No. 2 diesel fuel. The estimates were based on data from previous studies, and were normalized to a common basis to facilitate comparisons among the candidate fuels. The entire resource through end-use cycle was included in calculating both petroleum use and greenhouse gas emissions.

The estimates of petroleum use and GHGs reported in this study are based, in large part, on published values which vary widely and include significant uncertainty. This analysis did not address these variability and uncertainty issues. It is believed that these issues would have little impact on the relative values estimated in this study, though for values that are close together reversals in ranking are possible.

Fuels Investigated

The following fuels are included in this analysis:

Fuels compared to conventional, non-oxygenated gasoline in spark-ignition engines:

- reformulated gasoline containing 2.0 percent oxygen from MTBE. MTBE made using butanes from natural gas liquids and MTBE made using butane from petroleum were both considered.
- E85, considering ethanol made from both corn and cellulosic feedstocks
- M85, considering methanol made from both natural gas and coal
- propane, derived from both natural gas and from petroleum (crude oil refining)
- hydrogen made by steam reforming of natural gas and via electrolysis

Fuels compared to conventional diesel fuel in compression-ignition engines:

- clean diesel (low sulfur and low aromatics)
- naphtha
- biodiesel (B20 using soy methyl ester)
- synthetic diesel made from natural gas
- compressed and liquefied natural gas
- dimethyl ether made from natural gas via both one- and two-step processes
- diethyl ether made from ethanol derived from both corn and cellulosic feedstocks

RESULTS

The petroleum use and GHG emissions for several candidate fuels used in spark ignition engines are compared relative to the conventional, non-oxygenated gasoline in Figure 1. Data for fuels used in compression ignition engines are compared to conventional No. 2 diesel fuel in Figure 2. Estimates of petroleum use and GHGs were made over the full fuel cycle, including the processes of resource recovery, fuel refining and processing, fuel transport and delivery, and fuel use in the vehicle.

To facilitate comparisons among fuels, this analysis assumed that the fuel energy used by the vehicle, in Btu/mile, was unchanged for all fuels. For fuels compared to gasoline in spark-ignition engines, this value was 5,367 Btu per mile, corresponding to the current U.S. light duty vehicle population average fuel economy of 21.5 mpg. For heavy duty vehicle fuels, the basis was 32,175 Btu per mile, corresponding to 4 mpg average fuel economy for heavy duty vehicles. In the interest of having a common basis of comparison, the relative efficiency differences typical of alternative fuel vehicles were not taken into account.

Greenhouse gases associated with vehicle operations were calculated by adding the regulated emissions (Federal Tier 1 grams per mile) for carbon monoxide, non-methane hydrocarbons, and nitrogen oxides, to the carbon dioxide (CO_2) resulting from the combustion of the fuel, adjusted to account for the carbon species in the regulated emissions. Any CO_2 emissions from combustion of biomass are assumed to be recycled through the atmosphere during photosynthesis for biomass growth. Thus, the net CO_2 produced from combustion of biomass during fuel recovery and processing, as well as from vehicle operations, is considered to be zero.

Several of the fuels and fuel components included in this analysis were also studied by others (Wang, 1996, and Delucchi, 1991). In these instances, the previously reported data for petroleum use and associated GHGs was used after making appropriate adjustments to account for differences in assumed vehicle efficiency and in methods for calculating GHGs from vehicle operations. For fuels for which similar data were not found, the petroleum use and associated GHGs were calculated for each process stage by accounting for the typical raw material input and energy consumed during each stage. The energy consumed, based on estimates of process efficiency, was allocated among various fuels (residual oil, natural gas, coal, electricity, etc.) and fuel combustion processes in order to arrive at the petroleum used and resulting GHGs associated with that production stage.

A Note on Global Warming Potential

Quantities of various GHGs are expressed as the amount of CO_2 with an equivalent heat-absorbing capability. The conversion factor, or Global Warming Potential (GWP), is based on the direct radiative effect of the gas relative to CO_2, its longevity in the atmosphere, and its interactions with other atmospheric gases. GWPs used in this study were 1 for CO_2, 27.5 for methane (CH_4), and 320 for nitrous oxide (N_2O). Factors for carbon monoxide (CO) and other nitrogen oxides (NO_x) were set at zero based on the Intergovernmental Panel on Climate Change (IPCC) action to disavow previous GWP values for these gases. Note that, according to the IPCC, CO_2 equivalency values are generally in the range of plus or minus 35 percent.

DISCUSSION OF RESULTS

Reformulated Gasoline: Reformulated gasoline (RFG) takes more energy to produce than conventional gasoline because of more severe refining processing, and because it takes more energy to produce MTBE per Btu than gasoline. RFG using MTBE from butanes derived from natural gas liquids results in a slight decrease in petroleum use; making RFG using MTBE from refinery butanes slightly increases petroleum use. Greenhouse gases were judged to be essentially the same regardless of the origin of the butanes to make the MTBE.

Gasoline-Ethanol Blends: The reduction in petroleum use is essentially proportional to the ethanol content, with corn-derived ethanol displacing somewhat less due to the higher quantity of petroleum used in growing the crop and in producing the ethanol. The low greenhouse gas emissions associated with cellulosic ethanol are based on two assumptions: 1) biomass is used entirely to fuel the production plant; and 2), excess electricity is generated in the process and sold to the grid. A credit is taken for the GHGs which would have been produced by generating an equivalent amount of electricity by conventional means.

The petroleum used and GHG emissions from corn-derived ethanol are also highly dependent on coproduct credits, and would increase significantly without them. The method of assigning the credits also has a significant bearing on the outcome. In this analysis, the energy content of the ethanol and coproducts was used to apportion total petroleum used and GHGs produced. It was estimated that ethanol contains about 55 percent of the total energy in all of the products coming from corn-based ethanol plants, so 55 percent of the petroleum used and GHGs associated with corn production and ethanol processing was allocated to the fuel ethanol. The allocation of petroleum use and GHGs between fuel ethanol and coproducts can, alternatively, be based on their output weight (about 48% ethanol), on the relative market value of the products (about 70% assigned to ethanol), or on the replacement value of the coproducts (about 80% assigned to ethanol).[1]

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[1] Output weight allocation distributes petroleum use and GHGs among multiple products on the basis of their weight compared to the total weight of all products produced. Market value allocation makes the distribution based on the price of the ethanol compared to the total prices for all products. Replacement value allocation is based on taking credits equal to the petroleum and GHGs associated with producing a substitute product which the ethanol coproduct can replace. An example would be the energy and GHGs associated with producing soybean meal which can be used as a substitute for the corn gluten meal produced along with the fuel ethanol.

Gasoline-Methanol Blends: Methanol, whether derived from natural gas or from coal, results in substantial reduction in petroleum use. In both cases, however, GHGs are increased, especially when coal is the resource.

Propane: Propane is derived from both crude oil and natural gas. Propane derived from natural gas uses only a few percent of the petroleum used for conventional gasoline, and reduces GHG emissions by nearly 15 percent. Propane derived from petroleum uses almost as much petroleum (95%) as conventional gasoline, but results in only about 86 percent of the greenhouse gas emissions.

Hydrogen: Hydrogen may be used as a motor fuel either in combustion engines or in fuel cells. Production by most conventional methods would result in substantial petroleum displacement. Hydrogen produced by the steam reformation of natural gas results in only a very slight GHG reduction, while production via electrolysis using electricity from the grid results in an increase in GHGs due to the large percentage of coal used for electricity generation. Production of hydrogen via electrolysis using photovoltaic, hydropower, or nuclear generated electricity results in substantial petroleum and GHG reductions.

Clean Diesel, Naphtha, and Biodiesel: Clean diesel (low sulfur or California diesel) or naphtha offer insignificant benefits in either petroleum use or greenhouse gases compared to conventional diesel. Biodiesel (20% soy methyl ester and 80% conventional diesel fuel), on the other hand, could reduce petroleum use and GHGs by nearly 20 percent. A comprehensive study of biodiesel energy use is in progress (expected to be available soon) which will provide another data set and a check on these results.

Synthetic Diesel Fuel: There have been several references recently to processes that can convert natural gas to hydrocarbons in the diesel fuel boiling range. The reason these processes are now available is improved catalysts. Diesel fuel made using these processes would use very little petroleum (a few percent) but GHGs would be increased by about 25 percent because of the energy used in production of the fuel. This estimate is based on an assumed process efficiency for converting natural gas to synthetic diesel fuel of about 60 percent. Higher process efficiencies would, of course, reduce the GHGs. Moreover, if the gas used to produce the synthetic diesel was destined to be flared, the GHGs associated with fuel preparation and use could be reduced by the amount of GHGs which would have been produced by flaring, thereby significantly reducing the net GHGs.

Compressed and Liquefied Natural Gas: Using compressed or liquefied natural gas directly as a fuel uses almost no petroleum and reduces GHG by about ten percent due to the higher hydrogen-to-carbon ratio relative to conventional petroleum fuels.

Dimethyl Ether (DME) and Diethyl Ether (DEE): Use of dimethyl or diethyl ether results in a substantial reduction in petroleum use compared to conventional diesel fuel. Dimethyl ether, made by either a one-step or two-step process, results in an increase in GHGs. Diethyl ether made from ethanol derived from fermentation of corn results in a 20 percent increase in GHGs. Diethyl ether produced from cellulose-derived ethanol provides a greenhouse gas credit as a consequence of the sale of the excess electricity generated in the process being sold to the grid (see *Gasoline-Ethanol Blends*).

The Effect of Fuel Economy

Increasing vehicle efficiency has an immediate and positive impact on petroleum displacement and GHG reduction. This is illustrated in Figure 3, which shows the relative petroleum use and GHGs for conventional petroleum fuel vehicles with fuel economies covering the 20 to 80 mpg range. Note that the apparently higher rate of reduction in GHGs with increasing fuel economy is due to a carbon credit for the carbon-containing criteria emissions that are not counted as GHGs. (This difference is insignificant compared with the basic uncertainty of the GWPs of the major GHGs.)

The fuel economy factors in Figure 3 may be used in conjunction with other petroleum use and GHG data in this study to compare technologies with different fuel efficiencies. For example, to estimate the petroleum use and GHGs of a gas turbine-powered hybrid getting 80 mpg on synthetic diesel relative to a gasoline-fueled vehicle:

(a) determine the petroleum use and GHGs of synthetic diesel relative to conventional diesel fuel from Figure 2: 0.02 and 1.55, respectively
(b) determine the fuel economy factors from Figure 3: 0.260 for GHGs and about 0.265 for petroleum use.
(c) multiply the petroleum use and GHG values by the fuel economy factors to obtain relative petroleum use of 0.005 and GHGs of about 0.4 for synthetic diesel at 80 mpg vs gasoline at 21.5 mpg.

This calculation process is illustrated graphically in Figure 4.

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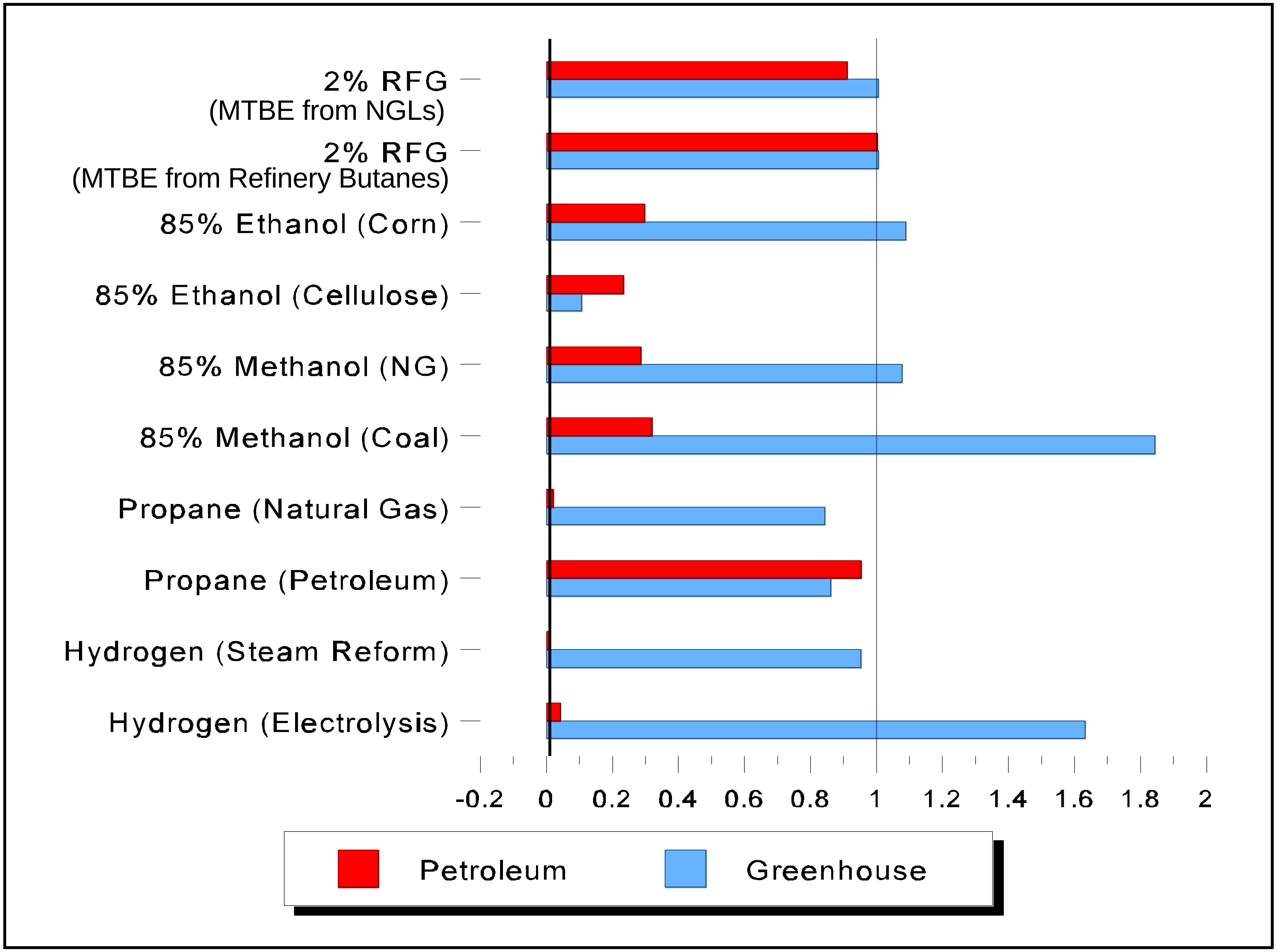

Figure 1. Petroleum Use and GHGs of Fuels Relative to Conventional Gasoline

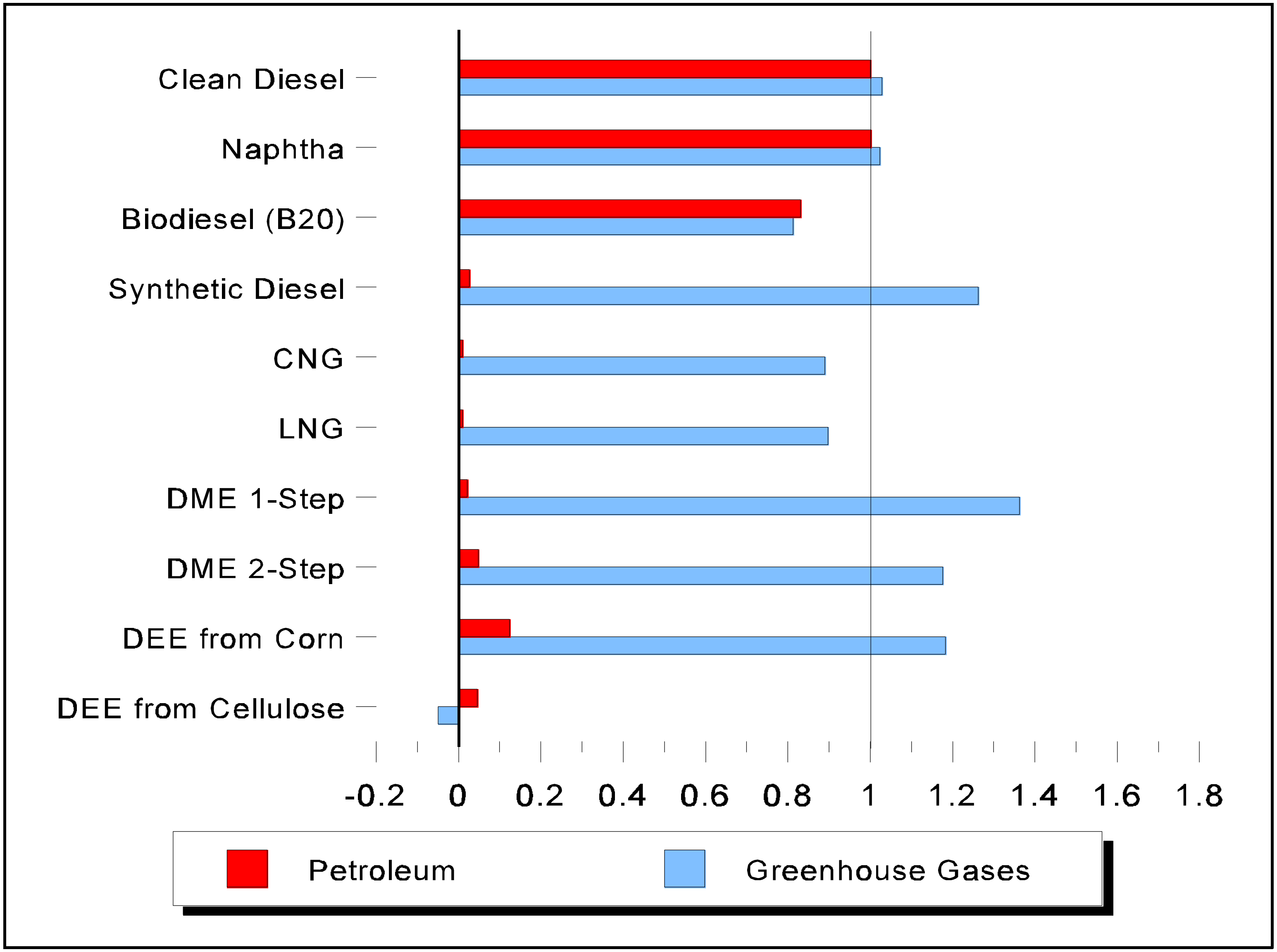

Figure 2. Petroleum Use and GHGs of Fuels Relative to Conventional Diesel Fuel

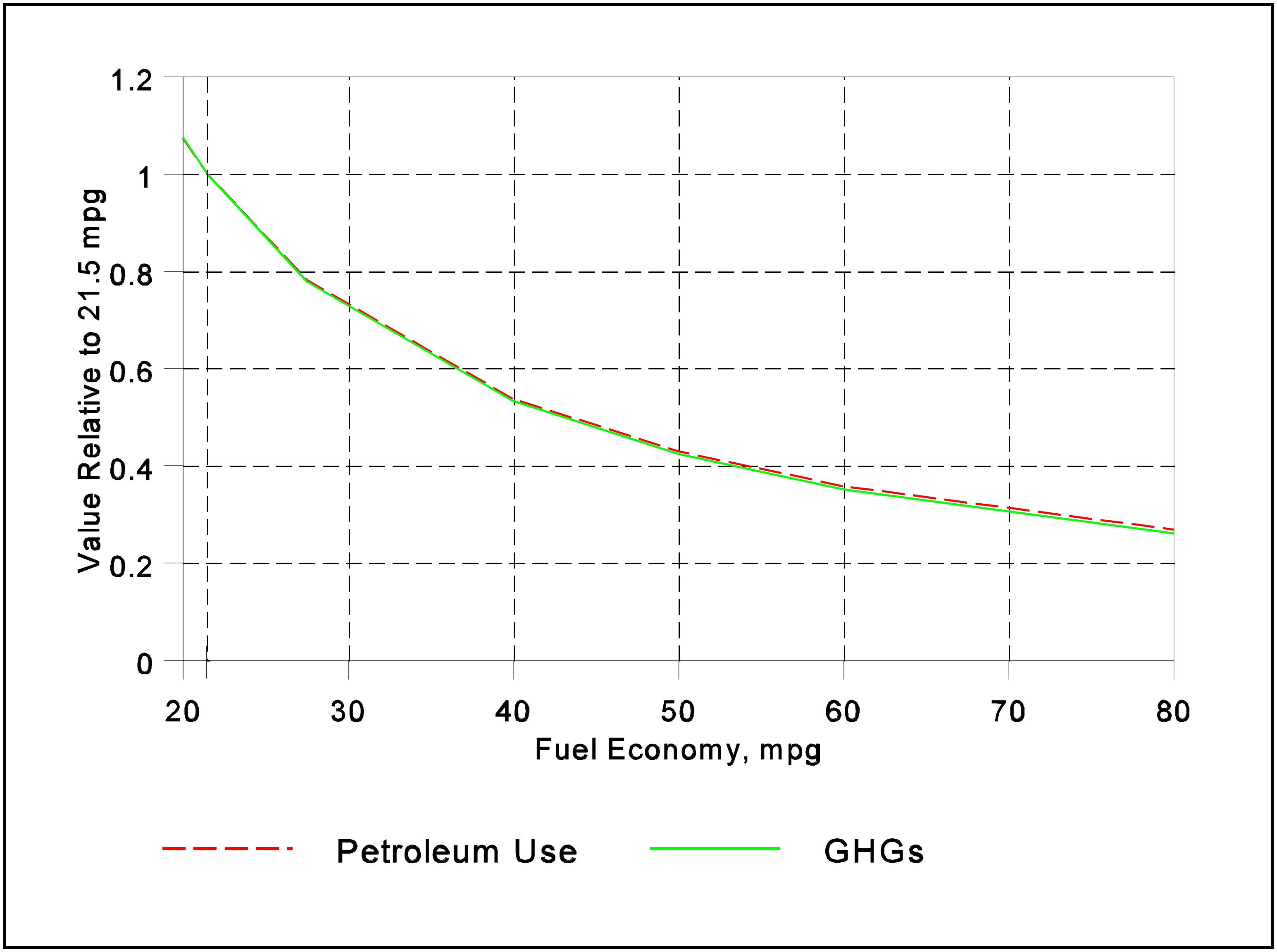

Figure 3. Effect of Fuel Economy on Petroleum Use and GHGs

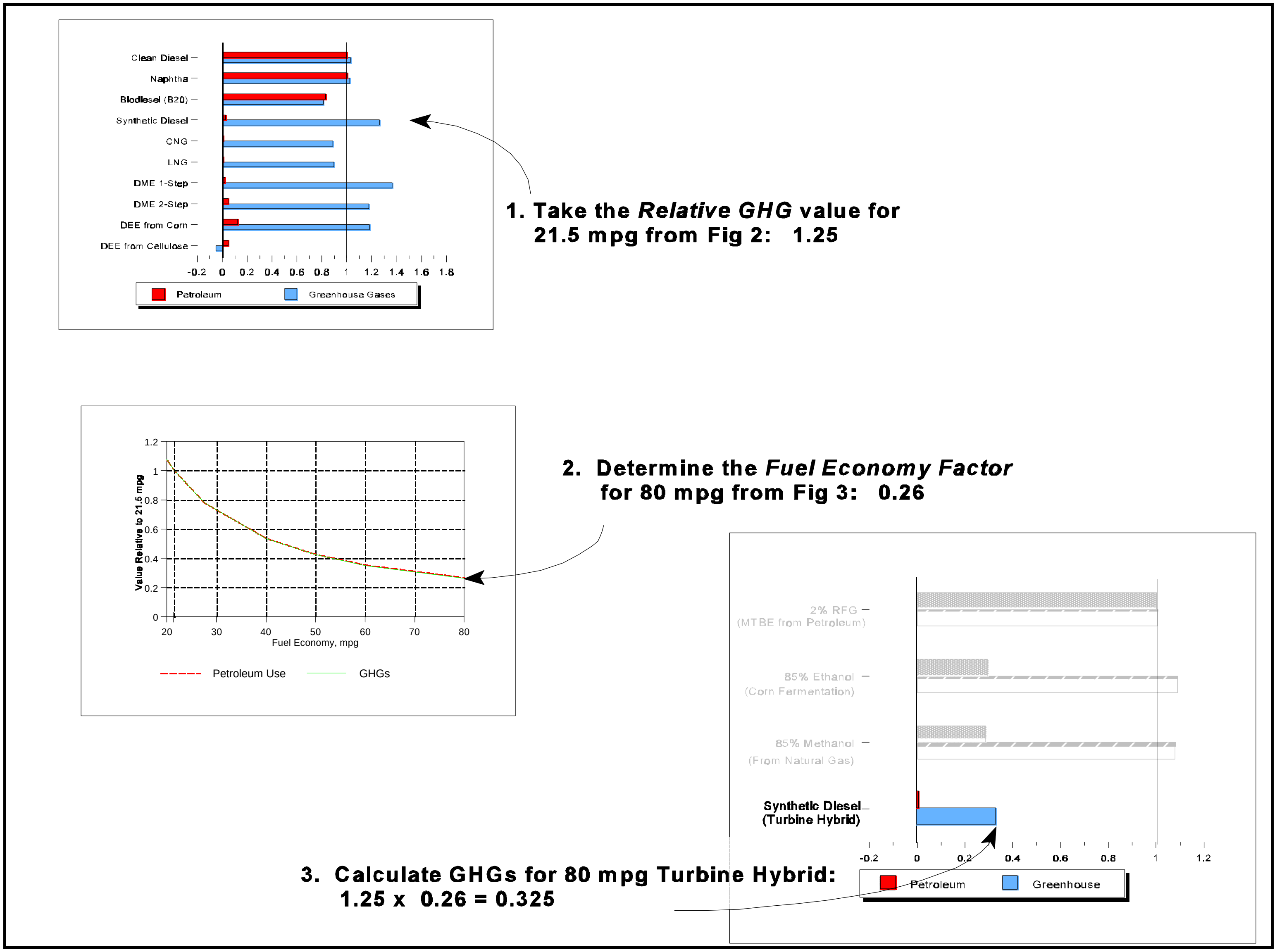

Figure 4. Sample Calculation of GHGs for 80 mpg Hybrid Vehicle Using Synthetic Diesel Fuel