reducing NO_x emissions. Use of diesel fuels in HEVs and CIDI engines may cause over 100% increases in urban NO_x emissions. Use of RFG, M85, LPG, or E10 has little or no effect on NO_x emissions. Use of CNGVs increases both urban and total NO_x emissions, primarily because of the NO_x emissions generated by the compressors used for NG compression. Use of E85 FFVs or LPGVs achieves small reductions in NO_x emissions. Use of EVs reduces urban NO_x emissions by more than 95%. Use of ethanol FFVs and EVs could increase total NO_x emissions.

The increases in total NO_x emissions for E85 and E10 result from the large amount of NO_x emissions released during production of ethanol. The increases in total NO_x emissions from diesel fuels are smaller than the increases in urban NO_x emissions.

Figure 6.29 shows large variations in fuel-cycle PM_{10} emissions. Use of diesel fuels causes increases of about 250% in urban PM_{10} emissions. Use of RFG or E10 has little effect on urban PM_{10} emissions. Use of CNGVs, LPGVs, or EVs achieves moderate reductions (near 40%). The relatively smaller reductions in urban PM_{10} emissions are partly attributable to tire- and brake-wear PM_{10} emissions, which are borne by each vehicle type, diluting the emission reduction effects of fuels and vehicle technologies.

Use of diesel fuels increases total PM_{10} emissions by about 160%. Use of E85 FFVs increases such emissions by six times, because of high upstream PM_{10} emissions during corn farming and ethanol production. Use of E10 or EVs with the U.S. and the U.S. Northeast generation mix results in moderate increases in total PM_{10} emissions. Use of CNGVs, M85 FFVs, LPGVs, EVs, or HEVs with the California generation mix, or of grid-independent HEVs fueled with RFG achieves moderate reductions in total PM_{10} emissions.

Figure 6.30 shows that total SO_x emissions increase with the use of EVs (except with the California generation mix) or ethanol (both E85 and E10). The increase in SO_x emissions by EVs with the U.S. generation mix is 4.5 times. The increases are caused by high SO_x emissions during electricity generation and ethanol production at ethanol plants. Use of other fuels and vehicles results in reductions in total SO_x emissions.

Use of any fuel or vehicle technology reduces urban SO_x emissions, although these reductions are smaller for diesel fuels and E10. For RFG, CNGVs, LPGVs, methanol FFVs, ethanol FFVs, EVs, and HEVs, reductions in urban SO_x emissions are above 80%.

6.4.2 Long-Term Technologies

The next 36 figures show changes in fuel-cycle energy use and emissions for various long-term transportation fuels and advanced technologies relative to conventional GVs fueled with federal RFG2. The long-term technologies are divided into four groups: (1) vehicles equipped with conventional SI engines and SIDI engines fueled with various SI engine fuels; (2) grid-independent (GI) and grid-connected (GC) HEVs equipped with SI engines and SIDI engines powered by various SI engine fuels; (3) vehicles equipped with CIDI engines (including CIDI standalone vehicles), GI HEVs, and GC HEVs; and 4) EVs and FCVs. Because there are over 75 combinations of fuels and vehicle technologies for the long-term options, we created a chart

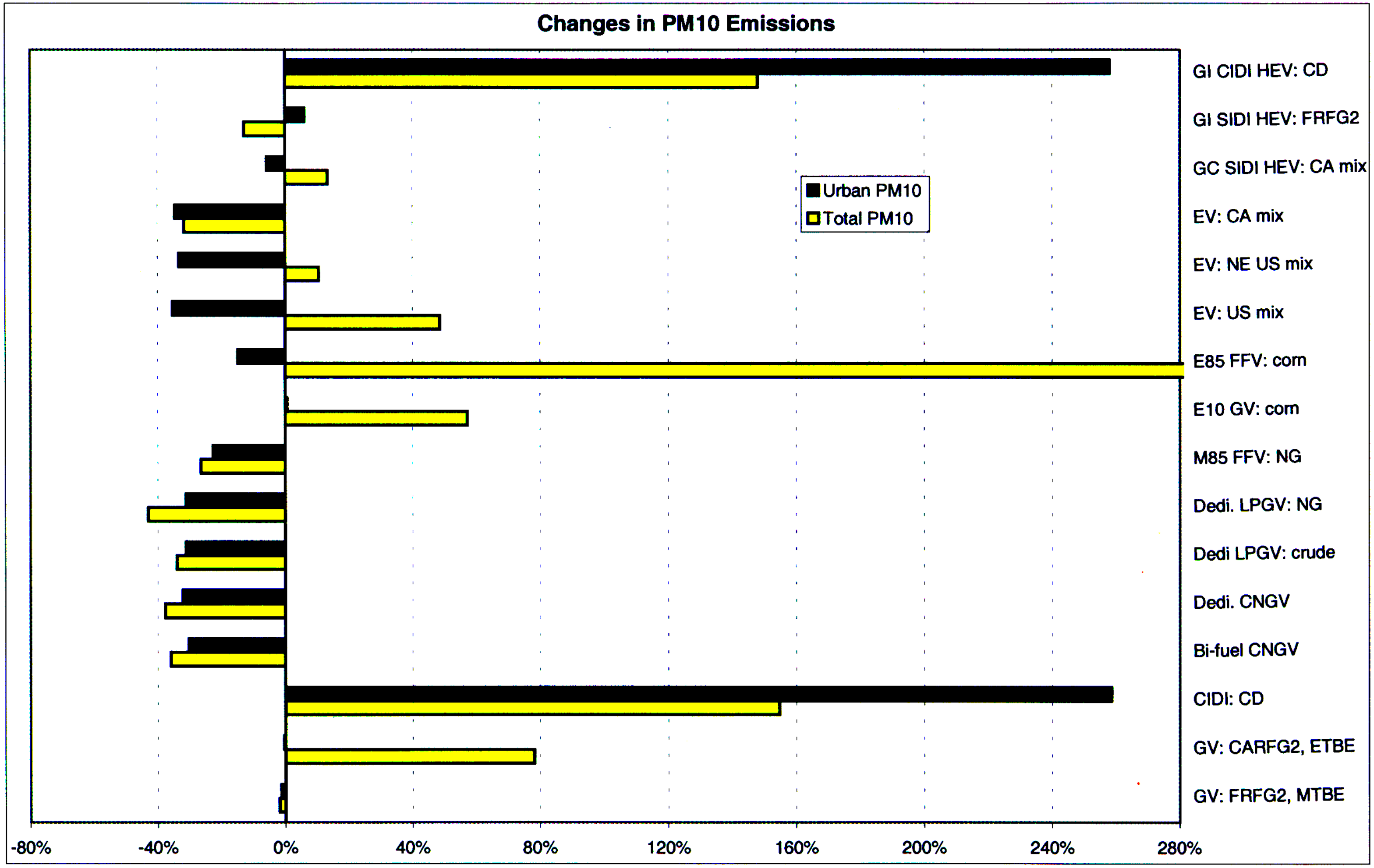

Figure 6.29 Changes in Fuel-Cycle PM_{10} Emissions Relative to GVs Fueled with CG: Near-Term Technologies

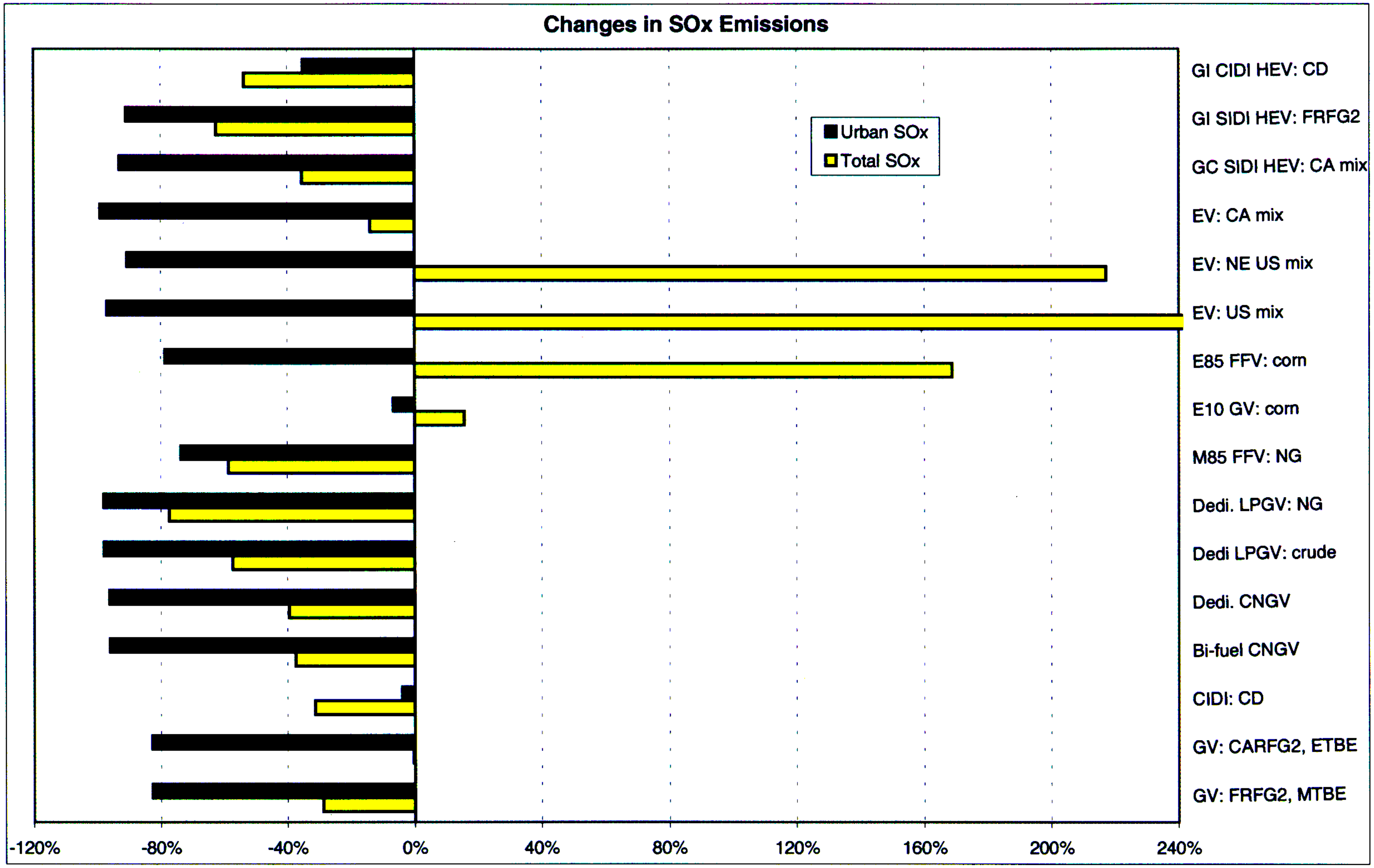

Figure 6.30 Changes in Fuel-Cycle SO_x Emissions Relative to GVs Fueled with CG: Near-Term Technologies

for each of the four groups and for each energy or pollutant to show fuel-cycle energy and emission effects.

Figures 6.31 through 6.34 show changes in fuel-cycle total energy use. Figure 6.31 shows total energy changes for SI and SIDI vehicles. Use of methanol from commercial natural gas or flared gas or ethanol from corn, woody biomass, or herbaceous biomass results in increased total energy use (note that total energy use includes the energy contained in corn and biomass that eventually comes from solar energy through the photosynthesis process). These increases are caused by the large amount of energy consumed during methanol or ethanol production. Use of LPGVs and SIDI vehicles fueled with RFG and methanol from landfill gases results in 15–20% reductions in total energy. The reduction by LPGVs is primarily because only a small amount of energy is consumed during LPG fractionating in petroleum refineries or in NG processing plants. The reductions by SIDI vehicles in general are attributable to their increased fuel economy.

Figure 6.32 shows reductions in total energy use by SI and SIDI HEVs. Technology options here include GI and GC HEVs. Conventional SI engines rather than SIDI engines were assumed for LPG, CNG, and LNG, because no significant fuel economy benefits are offered by replacing SI engines with SIDI engines for these fuels. On the other hand, SIDI engines were assumed for RFG, methanol, and ethanol. Large reductions (35–45%) are achieved for these vehicle types except for HEVs fueled with ethanol produced from woody and herbaceous biomass, for which reductions are 10–20%. The lower reductions for these options are caused by the large amount of energy consumed in cellulosic ethanol plants.

Figure 6.33 shows reductions in total energy use by CIDI standalone vehicles and CIDI HEVs. The former achieves 10–30% reductions, and the latter achieves over 40% reductions. Use of DME and FT50 results in lower reductions than use of other CI engine fuels because production of DME and FTD consumes a significant amount of energy.

Figure 6.34 presents reductions in total energy use by EVs and FCVs. Except for FCVs fueled with cellulosic ethanol (reductions of 10–20%), all the vehicles reduce total energy use by 40–60%. The smaller reductions by cellulosic ethanol are caused (again) by the large amount of energy consumed in cellulosic ethanol plants.

The four figures together show that SIDI HEVs, CIDI HEVs, and FCVs achieve large reductions in total energy use because of their significant improvements in vehicle fuel economy relative to gasoline SI engine technology.

Figures 6.35 through 6.38 present changes in fuel-cycle fossil energy use for the four technology groups. Figure 6.35 shows that, among the SI and SIDI vehicles, use of methanol produced from NG results in about a 10% increase in fossil energy use because of the large amount of NG consumed in methanol plants. On the other hand, use of flared gas- or landfill gas-based methanol results in 50–70% reductions in fossil energy because the energy contained in landfill gas or flared gas is otherwise wasted, and therefore it is not accounted for in GREET's fossil energy calculations. Use of CNG, LNG, and LPG achieves less than 20% reductions in fossil energy use. Use of ethanol reduces fossil energy use by 50% to over 80%

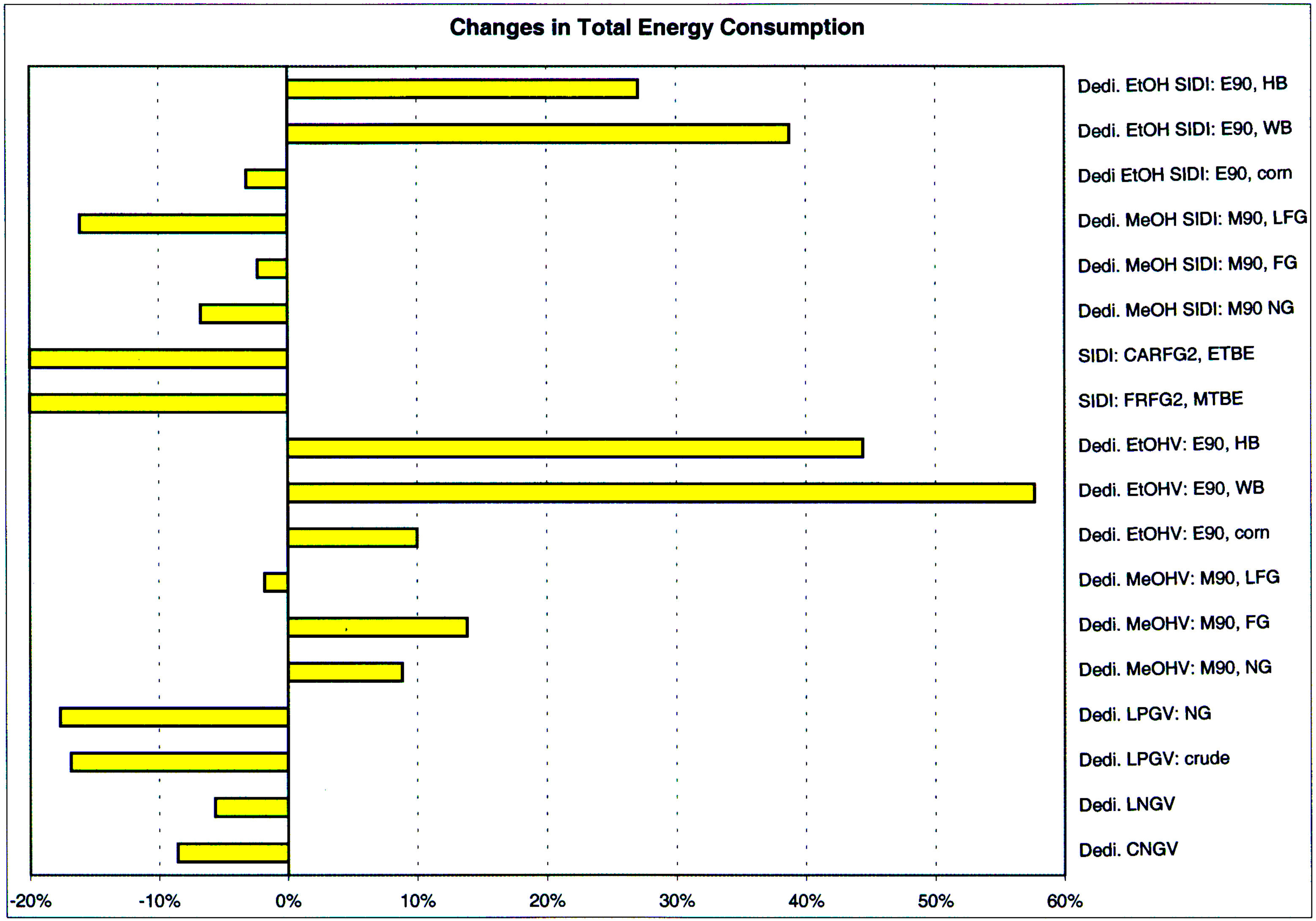

Figure 6.31 Changes in Fuel-Cycle Total Energy Use Relative to GVs Fueled with RFG: Long-Term SI and SIDI Vehicles

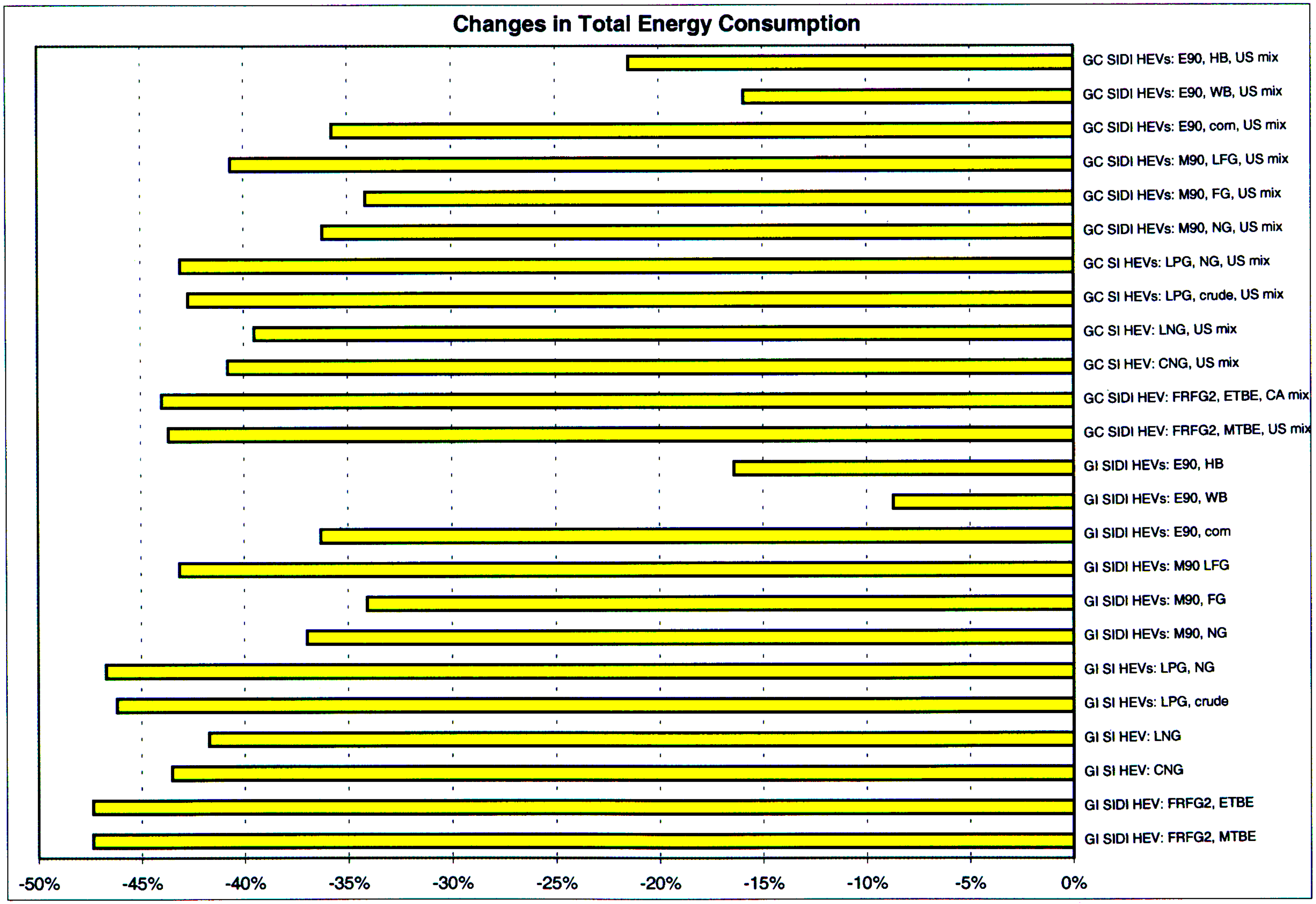

Figure 6.32 Changes in Fuel-Cycle Total Energy Use Relative to GVs Fueled with RFG: Long-Term SI and SIDI HEVs

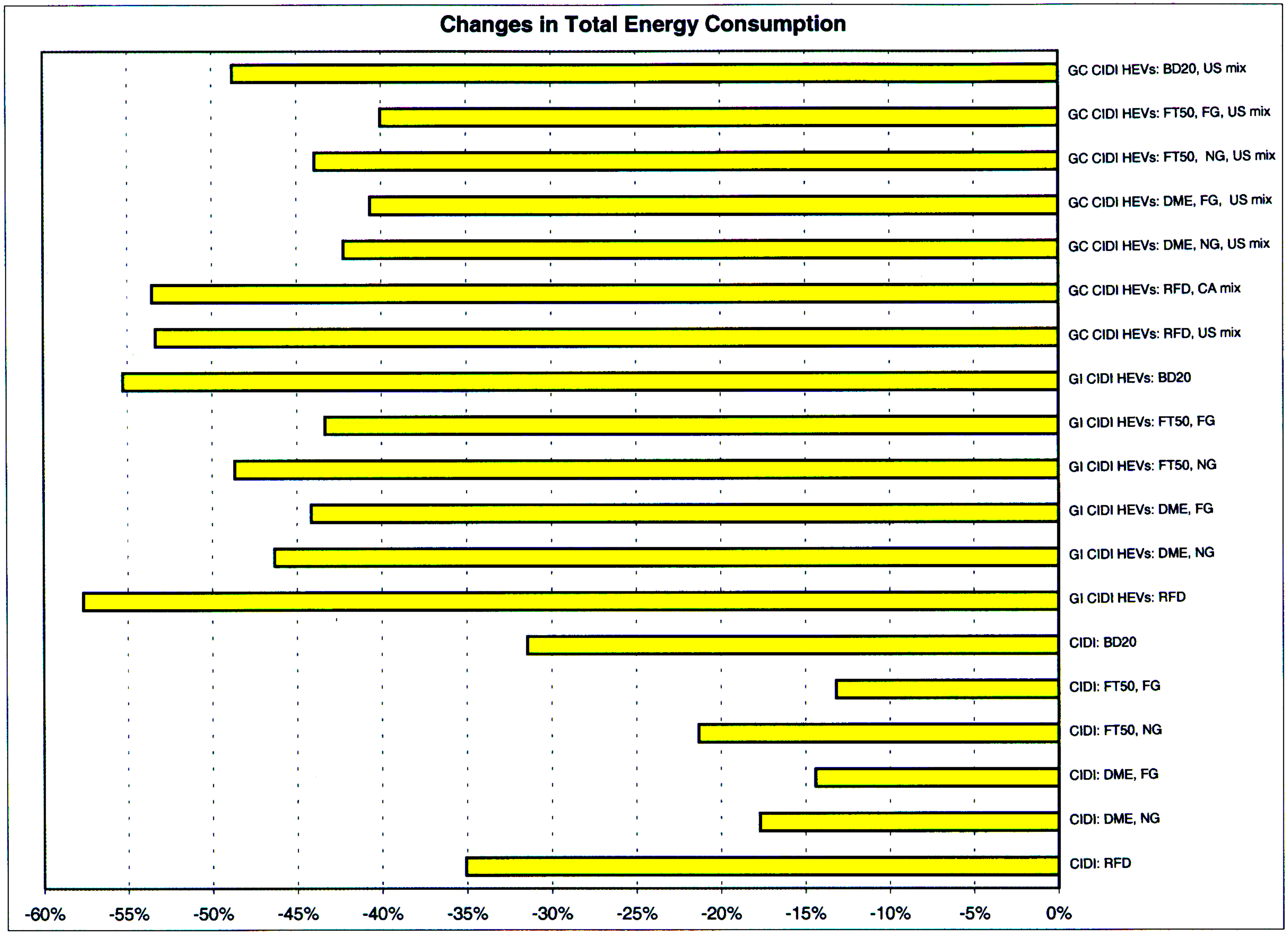

Figure 6.33 Changes in Fuel-Cycle Total Energy Use Relative to GVs Fueled with RFG: Long-Term CIDI Vehicles and CIDI HEVs

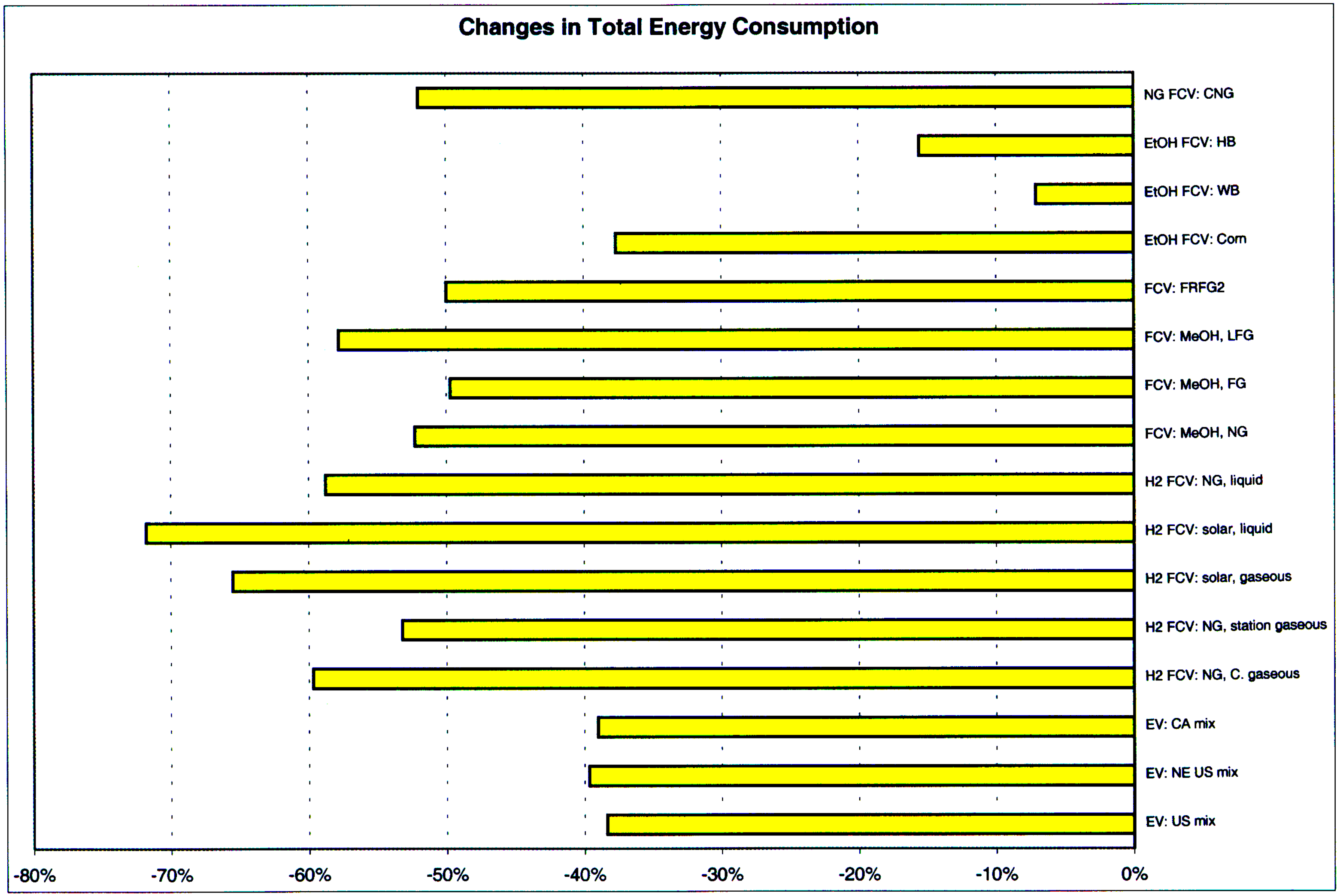

Figure 6.34 Changes in Fuel-Cycle Total Energy Use Relative to GVs Fueled with RFG: Long-Term EVs and FCVs

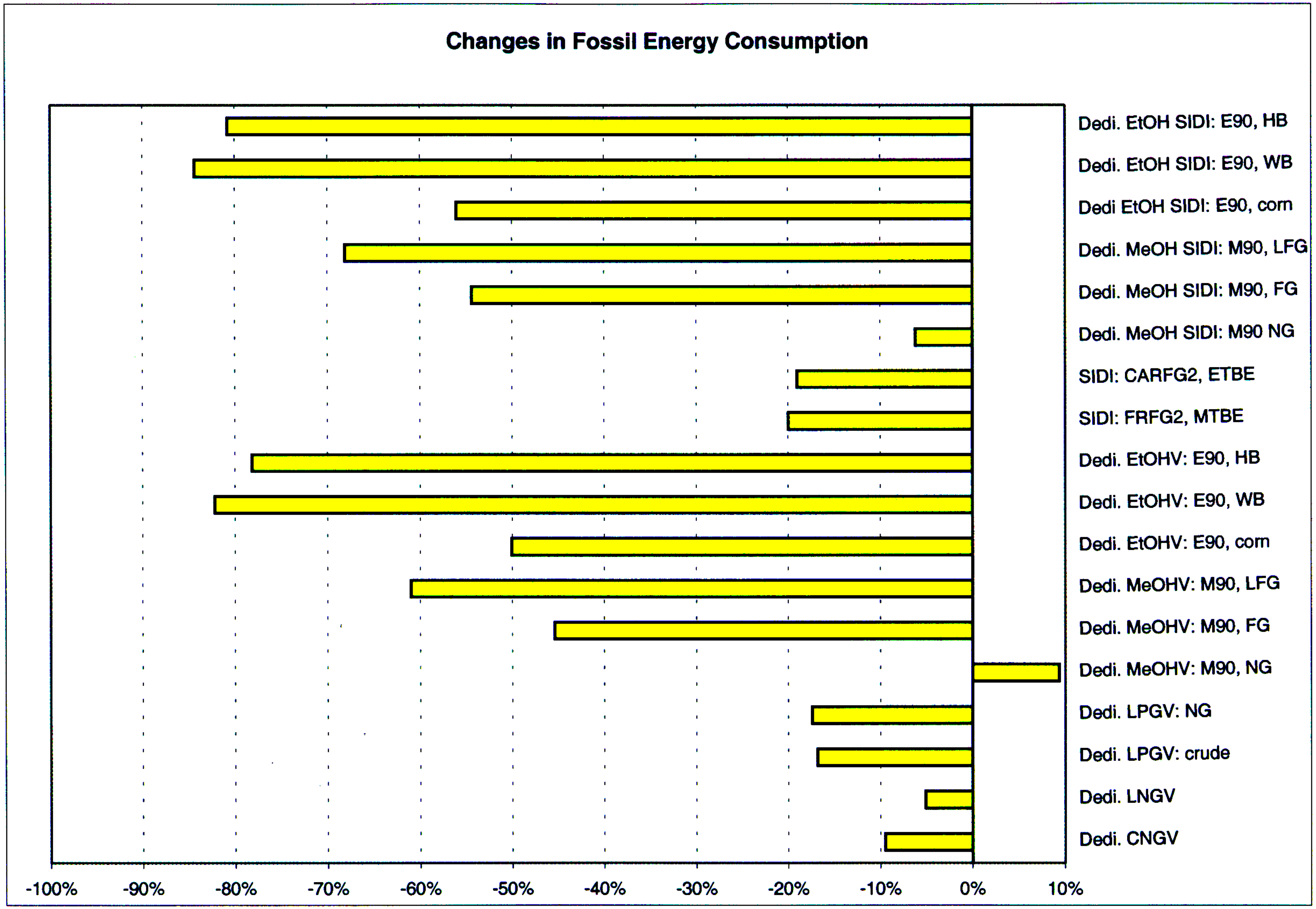

Figure 6.35 Changes in Fuel-Cycle Fossil Energy Use Relative to GVs Fueled with RFG: Long-Term SI and SIDI Vehicles

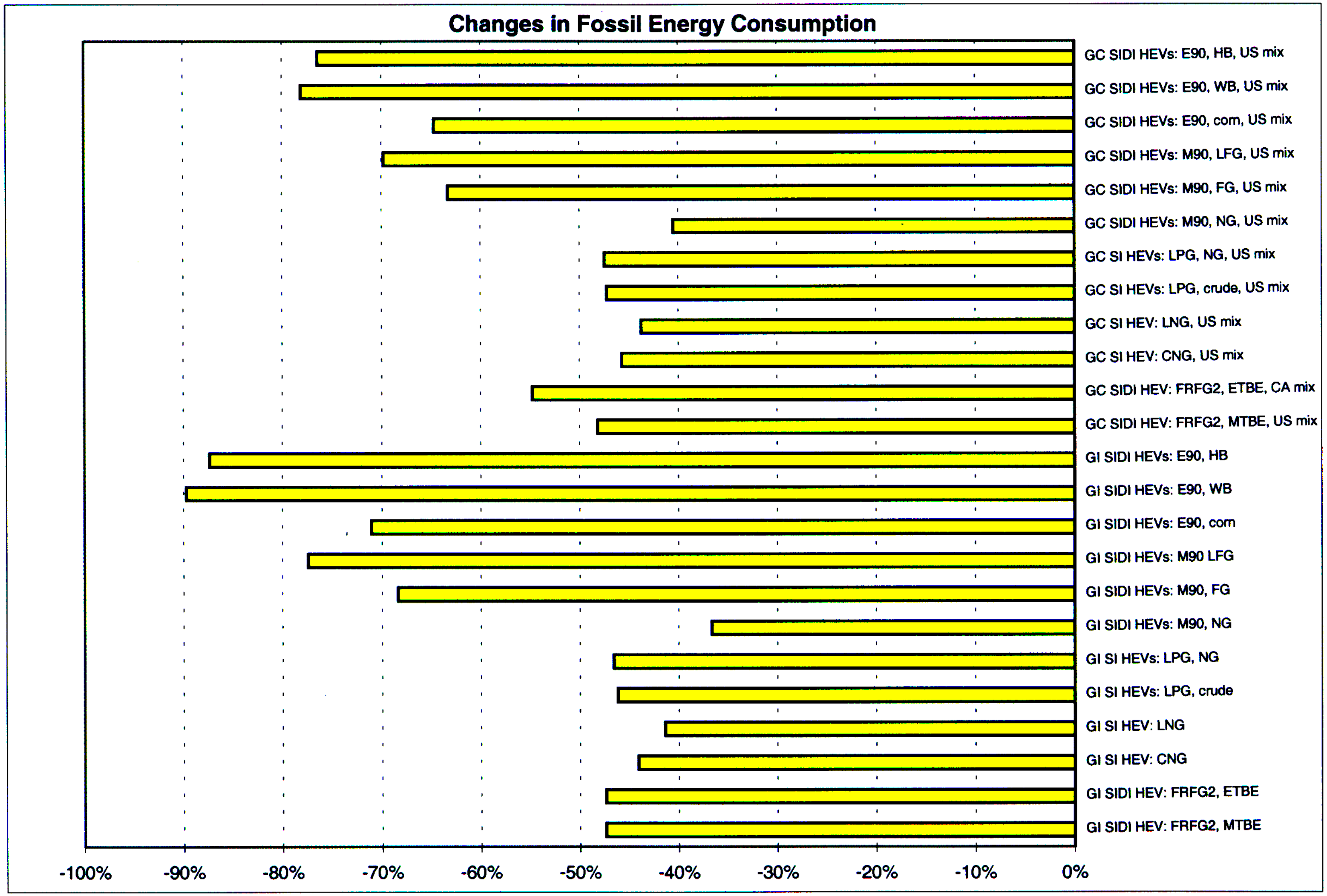

Figure 6.36 Changes in Fuel-Cycle Fossil Energy Use Relative to GVs Fueled with RFG: Long-Term SI and SIDI HEVs

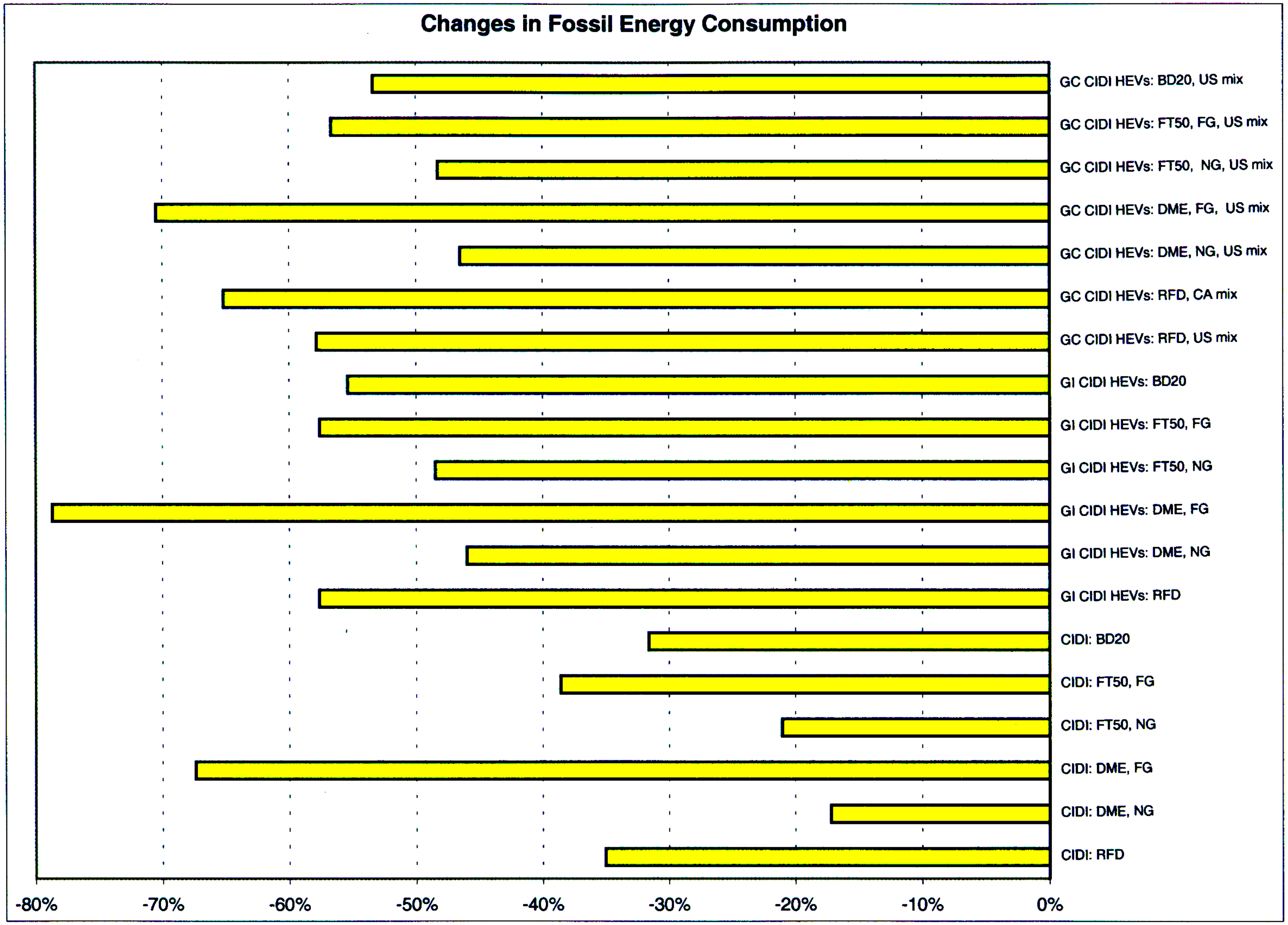

Figure 6.37 Changes in Fuel-Cycle Fossil Energy Use Relative to GVs Fueled with RFG: Long-Term CIDI Vehicles and CIDI HEVs

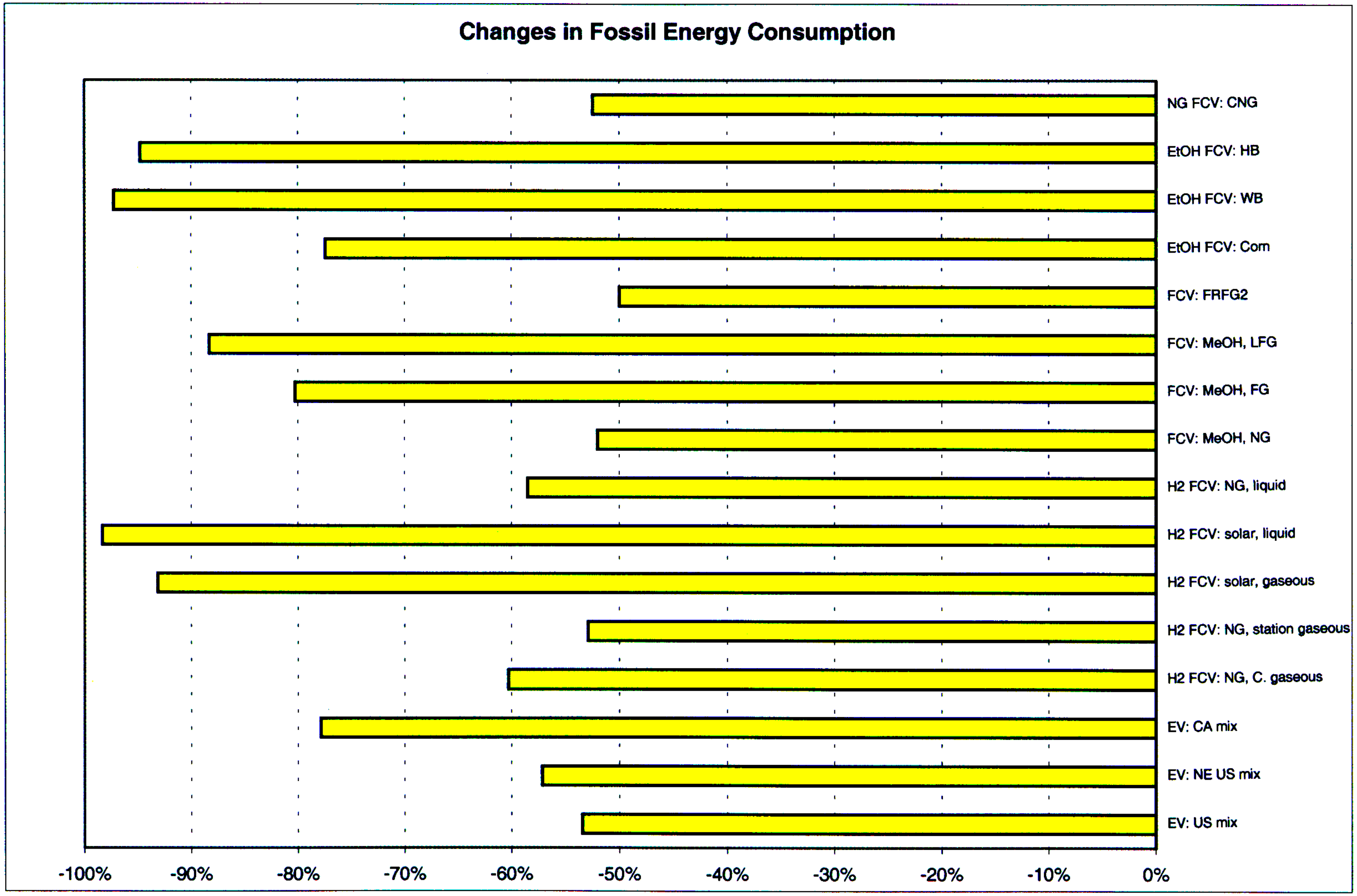

Figure 6.38 Changes in Fuel-Cycle Fossil Energy Use Relative to GVs Fueled with RFG: Long-Term EVs and FCVs

because the energy in ethanol eventually comes from solar energy during the photosynthesis process. Overall, advanced SIDI engines achieve greater fossil energy reductions than conventional SI engines.

Figure 6.36 shows reductions in fossil energy use by SI and SIDI HEVs. The magnitude of reductions can be separated into two distinct levels. At the first level, reductions range from 35% to 50%. Fuels include those produced from fossil energy sources (i.e., petroleum and natural gas). The reductions here are attributable to fuel economy improvements of the vehicle technologies. At the second level, reductions in fossil energy use reach 70–90%. Fuels include those produced from renewable sources (corn and biomass for ethanol) and waste energy sources (landfill gas and flared gas for methanol). The reductions here are attributable to vehicle fuel economy improvements and use of non-fossil energy sources.

Figure 6.37 presents fossil energy reductions by CIDI vehicles and CIDI HEVs. Use of DME and FT50 in CIDI vehicles achieves about 20% reductions. The small reductions are caused by inefficiencies in DME and FTD production. Use of all the CI engine fuels in HEVs achieves greater-than-50% reductions in fossil energy use because of the significant increases in fuel economy by these vehicles.

Figure 6.38 shows reductions in fossil energy use by EVs and FCVs. Again, the reductions are at two distinct levels. At the first level, reductions between 50–60% are achieved. Vehicles at this level include EVs with the U.S. and Northeast U.S. electric generation mix and FCVs fueled with NG-based H_2, NG-based methanol, RFG, and CNG. Reductions by these vehicles are caused by improved vehicle fuel economy. The second level shows fossil energy reductions of 80–95%. Vehicles at this level include EVs with the California electric generation mix and FCVs fueled with H_2 from solar energy, landfill gas- and flared gas-based methanol, and ethanol. The additional reductions by these vehicles are attributable to use of renewable energy sources or waste energy sources.

Overall, the four figures show increased fossil energy reductions in the following order: SI, SIDI, CIDI, HEVs, EVs, and FCVs. Reductions are from two sources: improved vehicle fuel economy and substitution of fossil fuels (petroleum and natural gas) with non-fossil fuels (renewable and waste energy sources).

Figures 6.39 through 6.42 present petroleum use reductions by the long-term technology options. Figure 6.39 shows reductions by SI and SIDI vehicles. Use of petroleum-based LPG in SI vehicles has little effect on petroleum use. Use of RFG in SIDI vehicles achieves about a 20% reduction because of SIDI efficiency gains. Use of non-petroleum fuels achieves 80% to almost 100% reductions. The reductions of around 80% by M90 and E90 are attributable to the fact that 10% gasoline is used in these fuel blends. Figure 6.40 indicates petroleum use reductions by SI and SIDI HEVs. Introduction of HEVs helps increase petroleum reductions (compare with Figure 6.39). For example, use of M90 and E90 in HEVs can now achieve over 90% reductions. Figure 6.41 shows reductions by CIDI engines in standalone and hybrid applications. While improved fuel economy helps reduce petroleum use for all of the cases, use of non-petroleum fuels achieves further reductions. Note that the reductions with FT50 and BD20 are smaller because petroleum-based diesel is used in both blends. Figure 6.42 presents

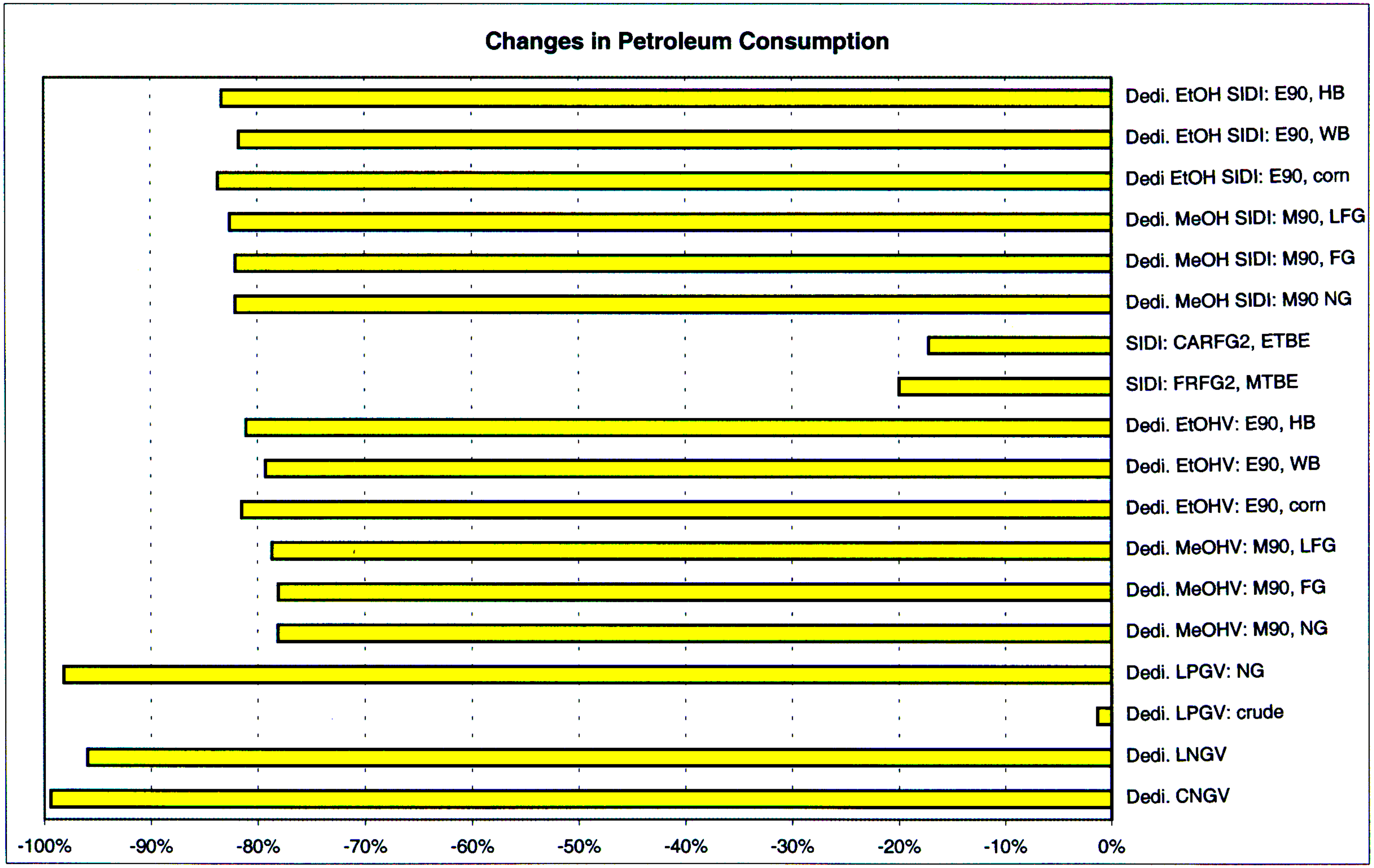

Figure 6.39 Changes in Fuel-Cycle Petroleum Use Relative to GVs Fueled with RFG: Long-Term SI and SIDI Vehicles

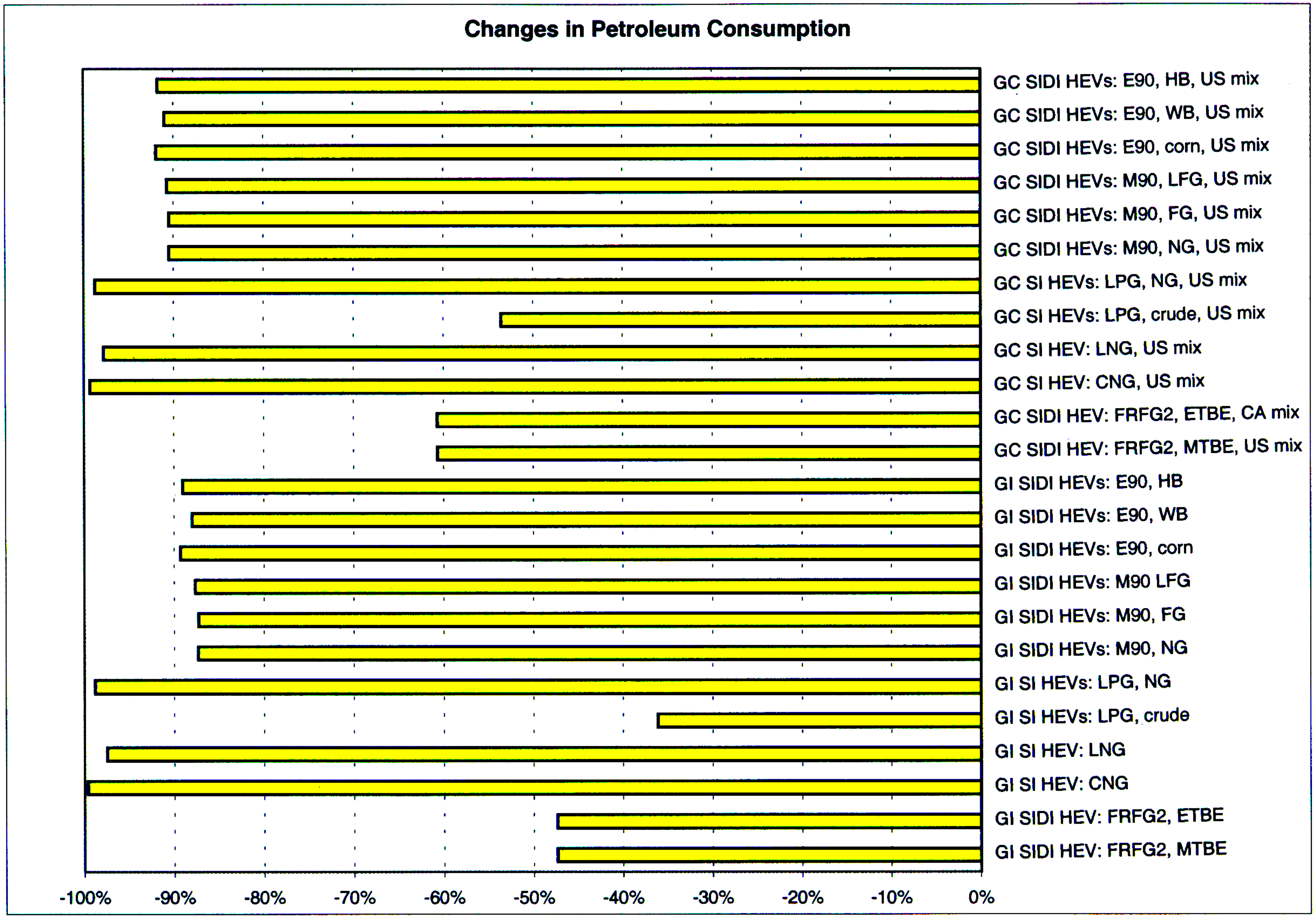

Figure 6.40 Changes in Fuel-Cycle Petroleum Use Relative to GVs Fueled with RFG: Long-Term SI and SIDI HEVs

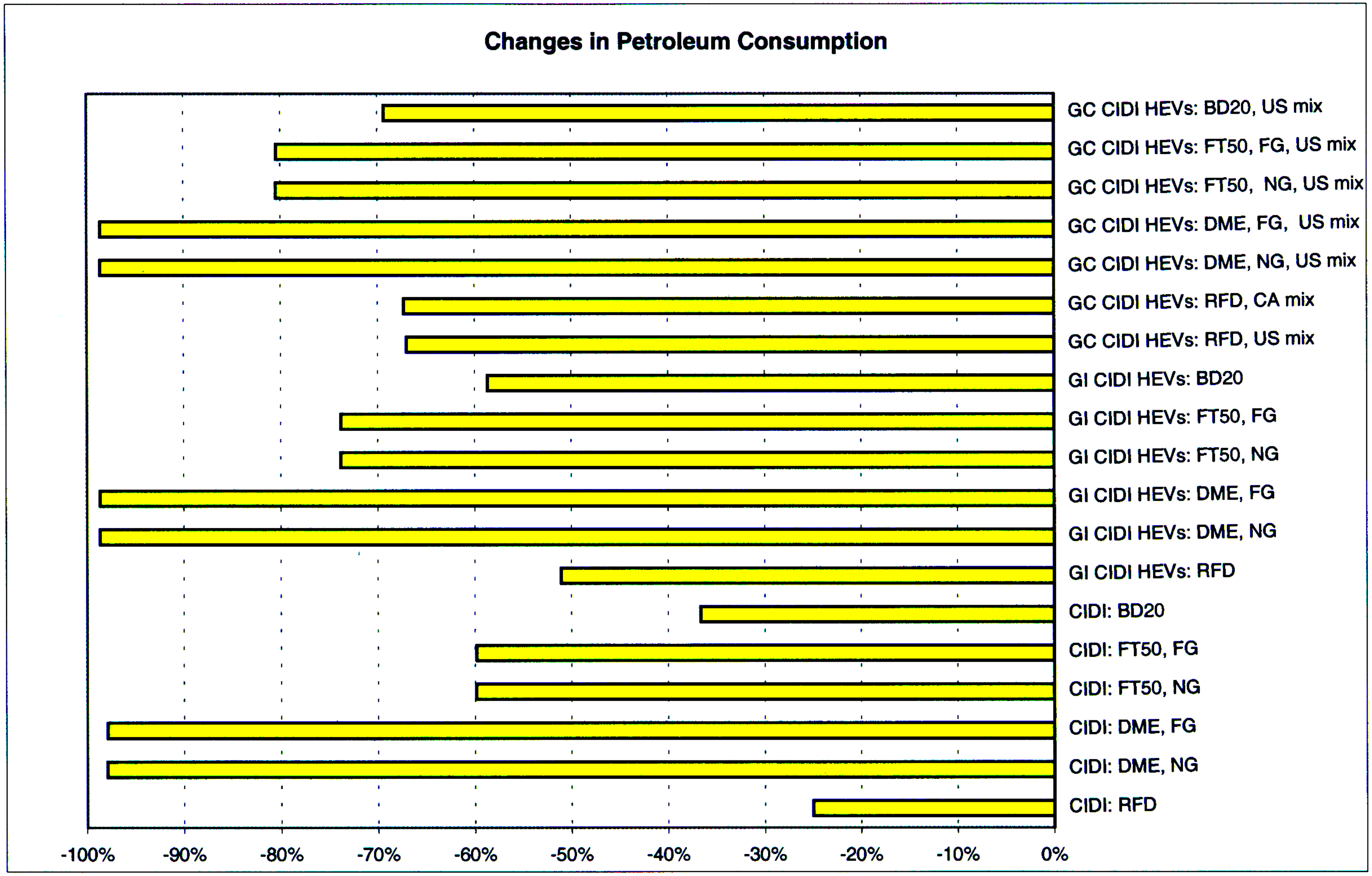

Figure 6.41 Changes in Fuel-Cycle Petroleum Use Relative to GVs Fueled with RFG: Long-Term CIDI Vehicles and CIDI HEVs

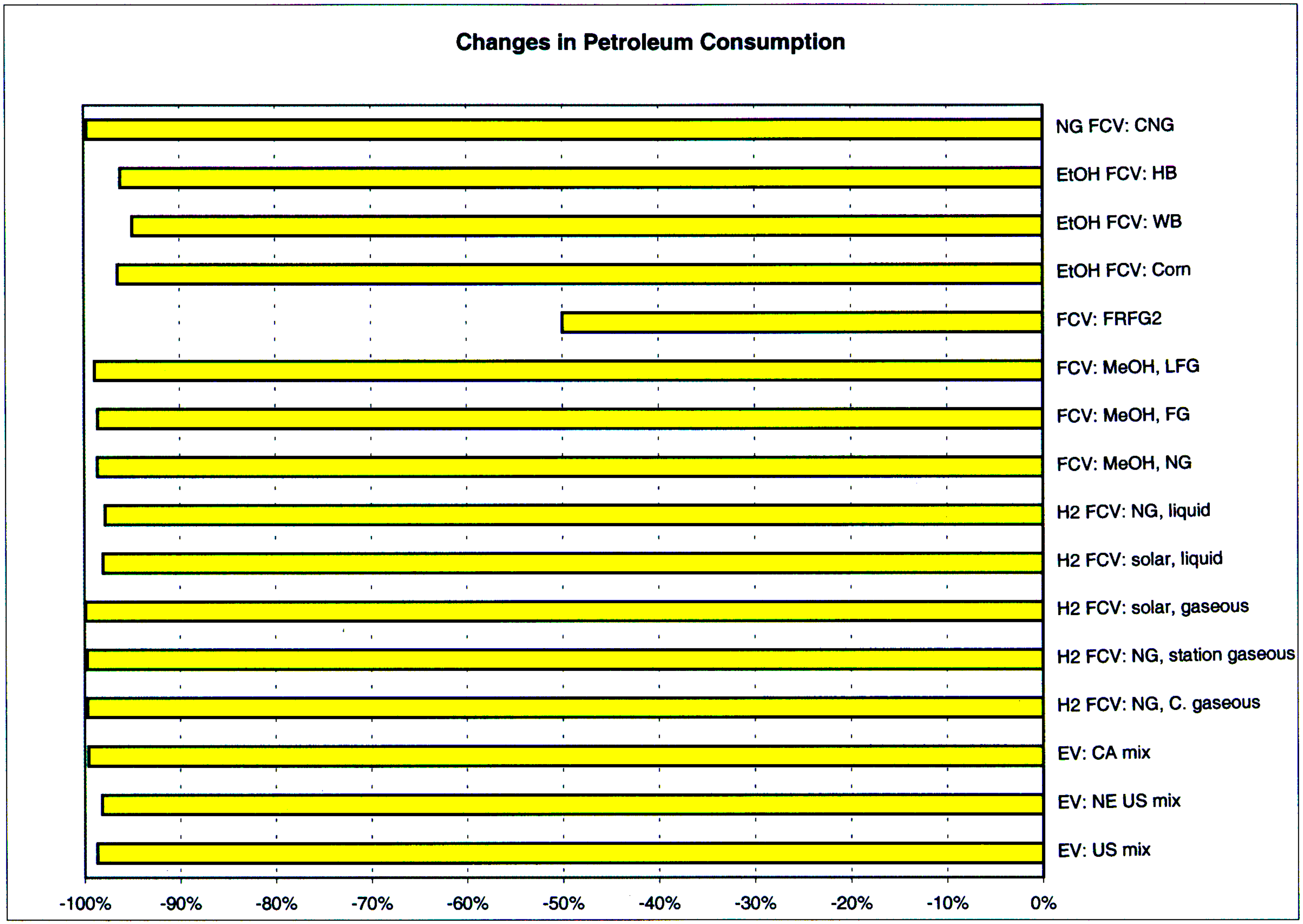

Figure 6.42 Changes in Fuel-Cycle Petroleum Use Relative to GVs Fueled with RFG: Long-Term EVs and FCVs

results for EVs and FCVs. Except for FCVs fueled with RFG, all of these cases nearly eliminate petroleum use.

Again, the four figures show the increased benefits in petroleum reductions from SI engines to SIDI engines, to CIDI engines, to HEVs, to EVs, and to FCVs and the benefits of switching from petroleum-based to non-petroleum-based fuels.

Figures 6.43 through 6.46 present reductions in CO_2-equivalent GHG emissions by the long-term technologies. GHG emissions here include emissions of CO_2, CH_4, and N_2O. These emissions were converted into CO_2-equivalent emissions by using IPCC-adopted GWPs (1 for CO_2, 21 for CH_4, and 310 for N_2O). Figure 6.43 shows GHG emission reductions by SI and SIDI vehicles. Use of CNG, LNG and LPG in SI engines and RFG and M90 in SIDI engines achieves 20–25% reductions. Use of M90 in SI engines achieves about a 10% reduction. Use of ethanol made from corn reduces GHG emissions by 40–45%. Use of cellulosic ethanol and flared gas-based methanol results in 80–100% reductions. Use of landfill gas-based methanol reduces GHG emissions by over 140%. The large reductions by cellulosic ethanol are attributable to CO_2 sequestration during the photosynthesis process and to the GHG emission credits for the extra electricity generated in cellulosic ethanol plants. The large reductions by flared gas- and landfill gas-based methanol are attributable to elimination of CH_4 venting and CO_2 combustion emissions associated with gas flaring.

Figure 4.44 shows GHG emission reductions by SI and SIDI HEVs. Use of fossil energy-based fuels (RFG, CNG, LNG, LPG, and NG-based methanol) achieves around 50% reductions, mainly because of improved vehicle fuel economy. Use of fuels produced from renewable or waste energy sources results in much higher reductions. GC HEVs with the California electric generation mix achieve greater reductions than GI HEVs.

Figure 4.45 presents GHG emission reductions by CIDI vehicles and CIDI HEVs. Use of RFD, FT50, and BD20 in CIDI standalone vehicles reduces GHG emissions by 30–40%. Hybridization of CIDI engines helps increase GHG emission reductions to above 50%. Use of DME and FTD produced from flared gas reduces GHG emissions even further.

Figure 4.46 shows GHG emission reductions by EVs and FCVs. EVs with the U.S. electric generation mix and FCVs powered by RFG achieve about 50% reductions. EVs with the Northeast U.S. and California generation mixes achieve additional reductions. FCVs fueled with NG-based H_2, NG-based methanol, corn-based ethanol, and CNG achieve 60–70% reductions. Use of solar H_2, flare gas- and landfill gas-based methanol, and cellulosic ethanol in FCVs results in over-90% reductions.

Overall, large GHG emission reductions are achieved by using advanced engine and vehicle technologies that have much higher fuel economy than baseline GVs and by switching from fossil energy-based fuels to renewable fuels. The results here quantitatively show the effects of fuel economy improvements and alternative fuels on motor vehicle GHG emissions. The four figures also show the differences in CO_2 and GHG emission reductions. If CH_4 and N_2O emissions are not included (as for CO_2 emission changes only), GHG emission reductions by NG-based fuels and ethanol would be overestimated. This is because a significant amount of

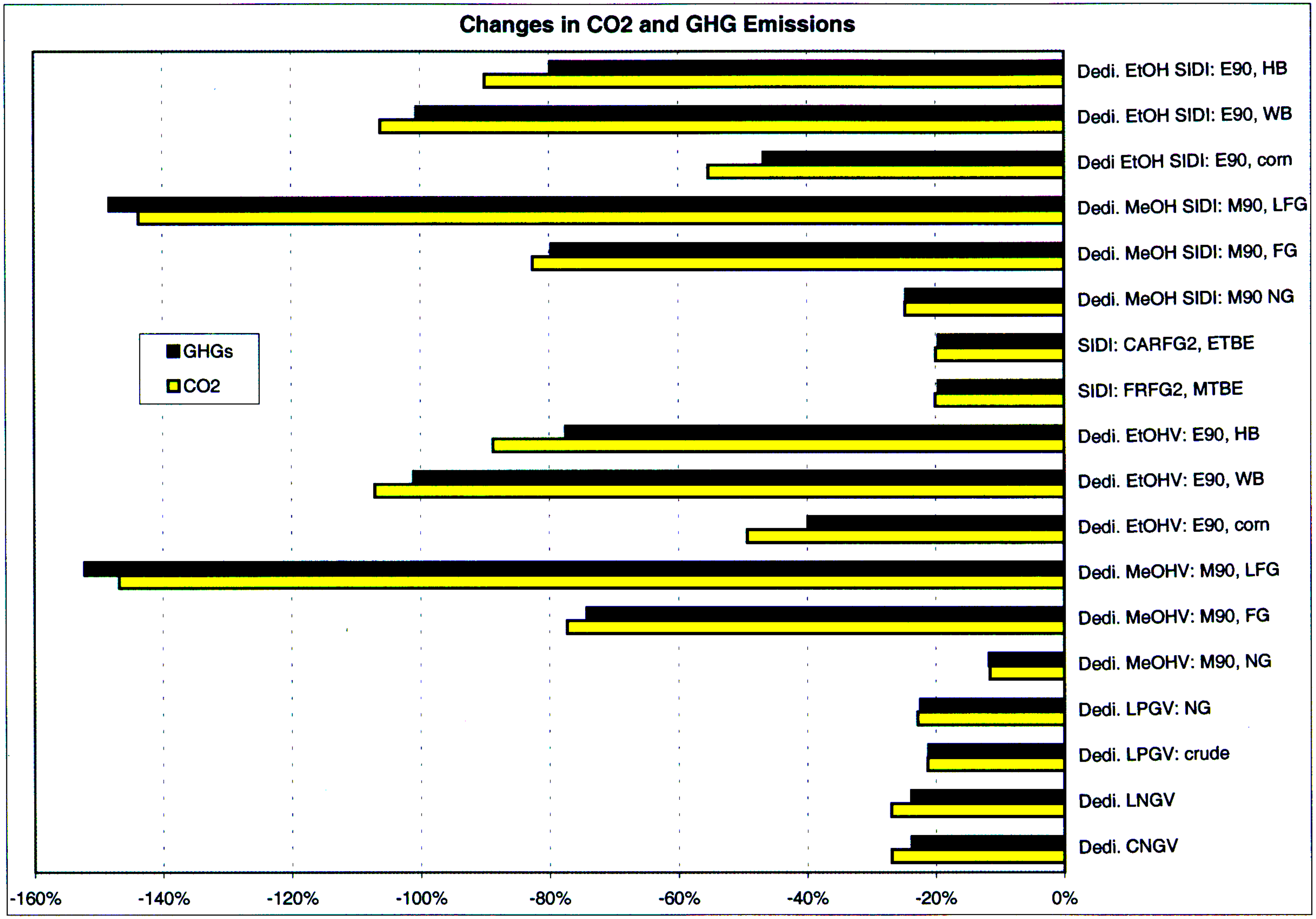

Figure 6.43 Changes in Fuel-Cycle CO_2-Equivalent GHG Emissions Relative to GVs Fueled with RFG: Long-Term SI and SIDI Vehicles

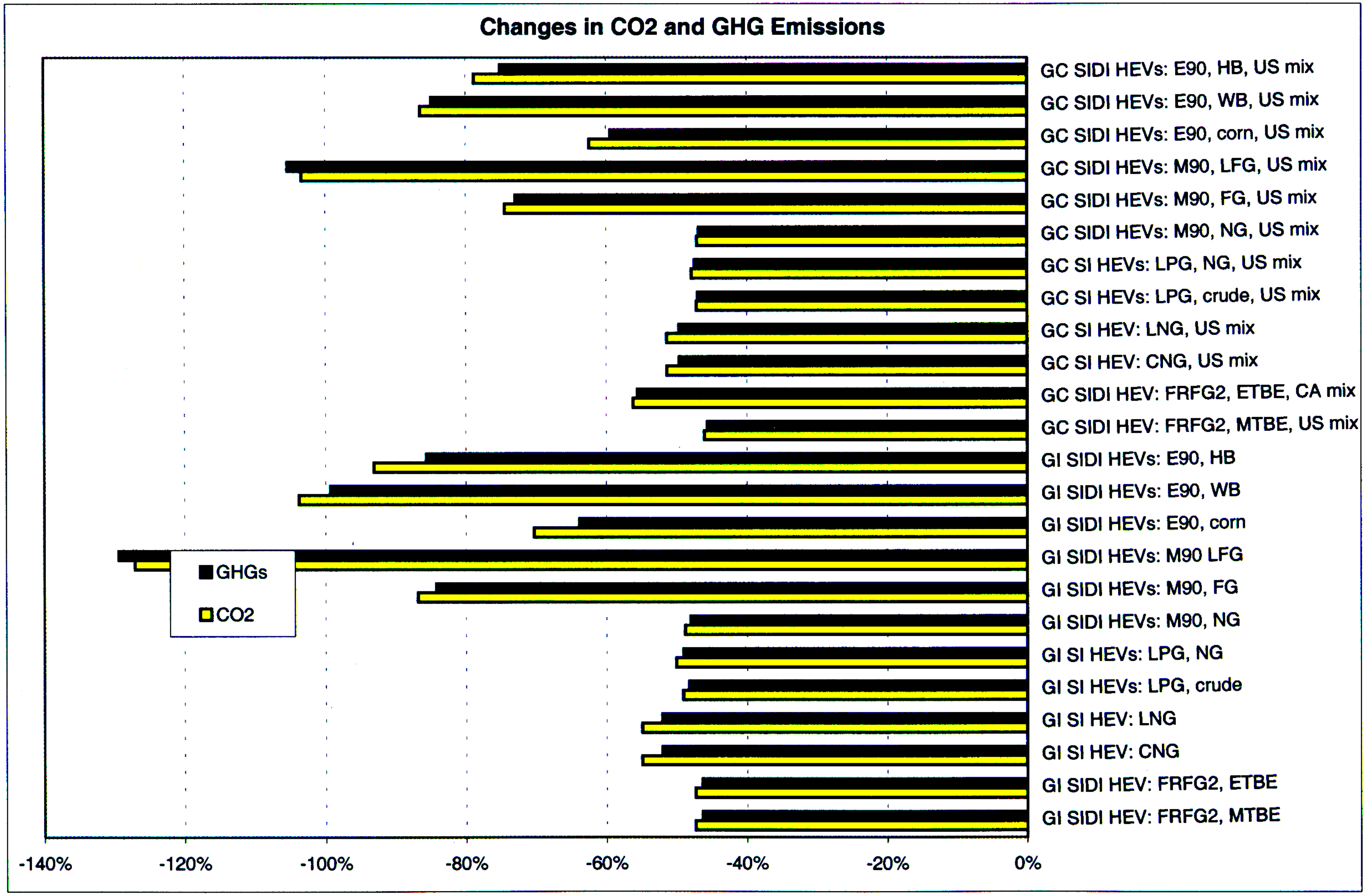

Figure 6.44 Changes in Fuel-Cycle CO_2-Equivalent GHG Emissions Relative to GVs Fueled with RFG: Long-Term SI and SIDI HEVs

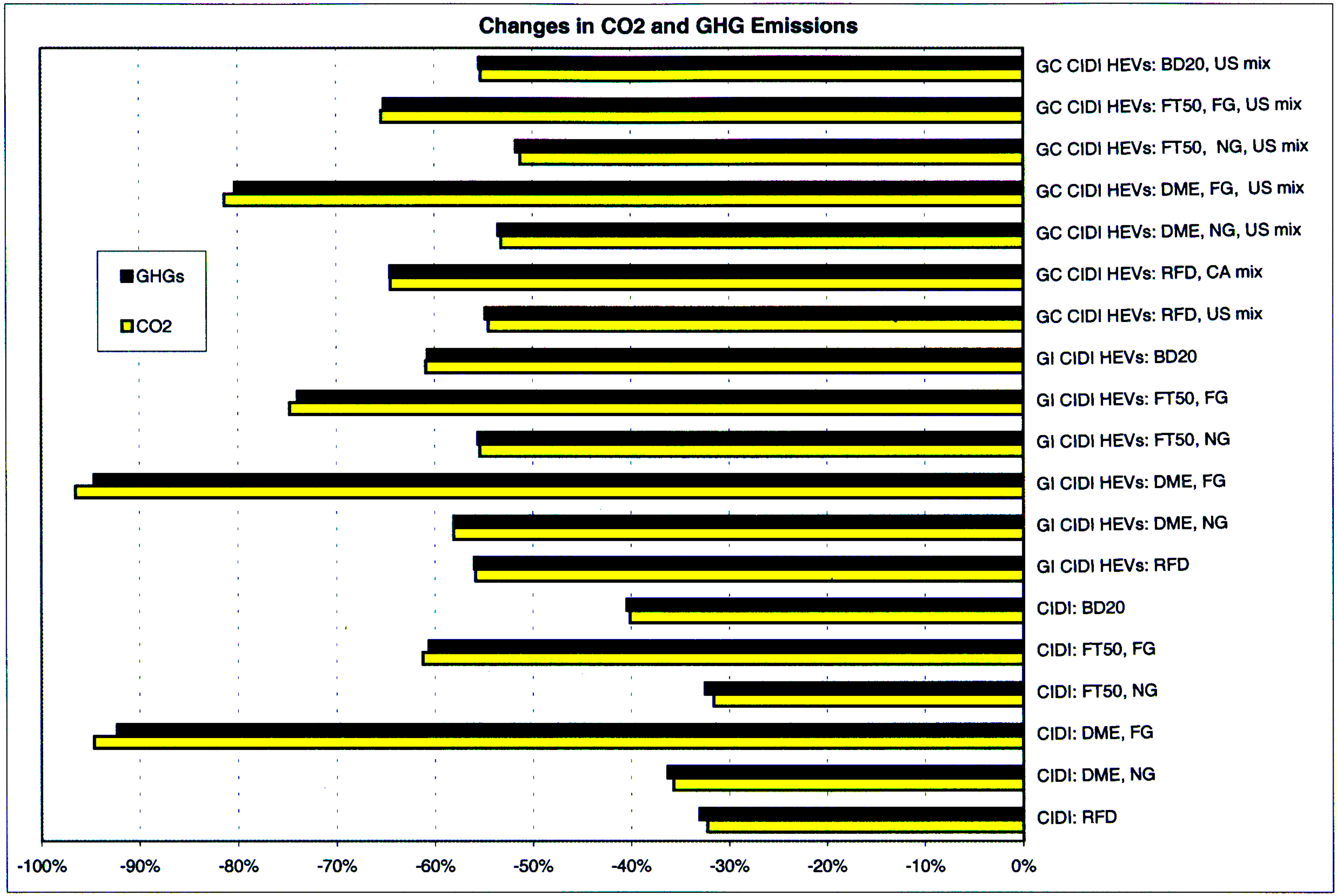

Figure 6.45 Changes in Fuel-Cycle CO_2-Equivalent GHG Emissions Relative to GVs Fueled with RFG: Long-Term CIDI Vehicles and CIDI HEVs

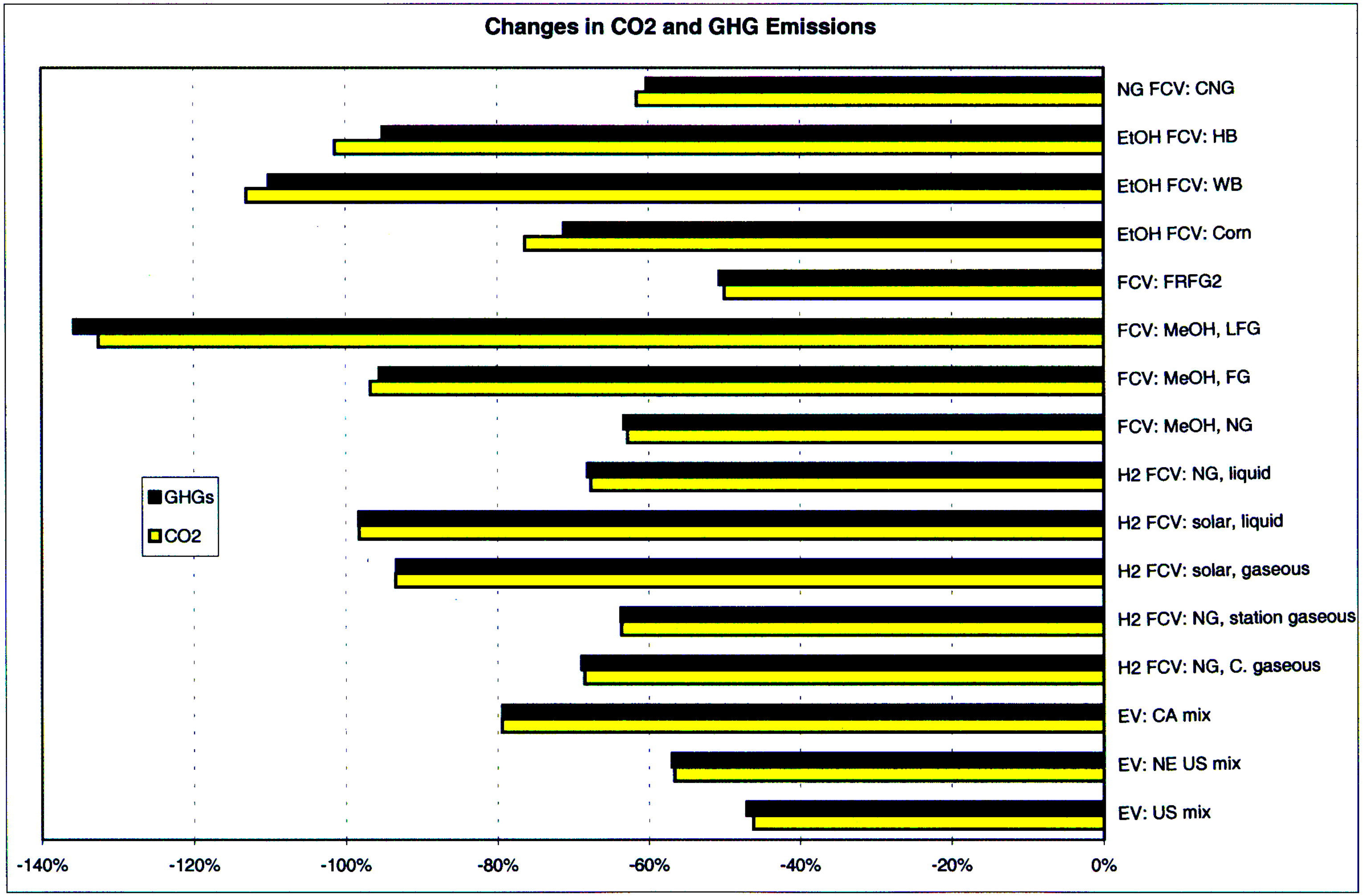

Figure 6.46 Changes in Fuel-Cycle CO_2-Equivalent GHG Emissions Relative to GVs Fueled with RFG: Long-Term EVs and HEVs

CH_4 emissions are associated with NG-based fuel pathways, and a significant amount of N_2O emissions results from nitrification and denitrification of nitrogen fertilizers in cornfields and biomass farms.

Figures 6.47 through 6.50 present changes in total and urban VOC emissions by the long-term technologies. For the five criteria pollutants, total emissions include emissions from fuel-cycle activities occurring everywhere, while urban emissions include emissions that occur only within urban areas; upstream emissions occurring outside of urban areas are excluded. Figure 6.47 shows VOC emission changes by SI and SIDI vehicles. Total VOC emissions are increased substantially by corn-based ethanol because of the VOC emissions from tractors used for corn farming and from ethanol production in ethanol plants. On the other hand, total VOC emissions are reduced by nearly 150% for flared gas-based methanol, which eliminates the VOC emissions associated with gas flaring during methanol production. Use of CNG, LNG, and LPG achieves 40–60% reductions in VOC emissions, primarily because VOC evaporative emissions from baseline gasoline vehicles are eliminated. VOC emission reductions by M90 and E90 vehicles are limited because these fuels still produce evaporative emissions.

Figure 6.48 presents VOC emission changes for SI and SIDI HEVs. Again, total VOC emissions are increased for corn-based ethanol, although the increase is much smaller. Total VOC emissions are significantly reduced by using flared gas-based methanol, which eliminates VOC emissions from gas flaring. Use of CNG, LNG, and LPG achieves about 50% reductions for GI HEVs and about 70% reductions for GC HEVs. In general, use of HEVs reduces both total and urban VOC emissions because of the vehicles' improved fuel economy, which helps reduce both upstream and vehicle evaporative emissions.

Figure 6.49 shows that use of CIDI standalone vehicles and CIDI HEVs achieves VOC emission reductions ranging from 40% to 80%, relative to use of GVs. The reductions result from elimination of GV evaporative emissions by CI fuels. Note that use of flared gas-based DME and FTD achieves huge reductions in total VOC emissions.

As Figure 6.50 shows, EVs and FCVs achieve uniform VOC emission reductions. Reductions by EVs and H_2- and CNG-fueled FCVs are almost 100% because these vehicles generate no tailpipe or evaporative VOC emissions. Reductions by FCVs fueled with methanol, ethanol, and gasoline are smaller because these fuels produce evaporative emissions, despite zero exhaust emissions.

Overall, the magnitude of VOC emission reductions is in the following order (from small to large): SI and SIDI standalone vehicles, SI and SIDI HEVs, CIDI vehicles and CIDI HEVs, and FCVs.

Figures 6.51 through 6.54 show changes in total and urban CO emissions by the long-term technology options. In Figure 6.51, use of CNG, LNG, and LPG reduces CO emissions by about 20%. Use of ethanol results in increased total CO emissions because of the high CO emissions associated with tractors used during farming and with ethanol production. Use of landfill gas-based methanol helps reduce both total and urban CO emissions by eliminating CO emissions from landfill gas burning. Other fuel options have little effect on CO emissions.