# 6 ENERGY USE AND EMISSIONS RESULTS

This section presents the energy use and emissions results for various vehicle technologies, as calculated by using the GREET model. In calculating fuel-cycle emissions, a 2000 model-year (MY) passenger car is assumed. We have also assumed that the baseline 2000-MY car fueled with RFG meets federal Tier 1 standards. While many of the assumed vehicle technologies for the 2000 MY are mature, others — including EVs, HEVs, and FCVs — are not. Immature fuel production technologies include woody biomass to ethanol and herbaceous biomass to ethanol.

To approximate life-cycle emissions for the assumed 2000-MY car, fuel-cycle emissions are calculated in calendar year 2005. By 2005, the 2000-MY car should accumulate about half of its lifetime vehicle miles traveled (VMT). Emissions from the 2000-MY cars in 2005, then, represent the approximate average of the car's lifetime emissions. For HEVs, we assumed that half of their vehicle miles are traveled using energy generated from the on-board gasoline engine, and the other half with grid electricity. Even in 2005, combustion technologies both with and without emission controls can be applied to many upstream stages. Where uncontrolled technologies are applicable, we assumed that 80% of combustion technologies are controlled and the remaining 20% are uncontrolled. Table 10 presents calculated per-mile energy use and emissions for all vehicle technologies included in the GREET model. Note that in the table, a negative number indicates an emissions saving credit.

Figures 4 through 12 show changes in fuel-cycle energy use and emissions of various transportation fuels relative to those of RFG. Data for these figures are presented in tabular form in the appendix. Figure 4 shows changes in fuel-cycle total energy use. Use of ethanol and NG-based methanol in internal combustion engines causes a 15-35% increase in total energy use. These increases are caused primarily by the significant amount of energy lost during ethanol and methanol production. On the other hand, use of FCVs fueled with methanol or hydrogen; HEVs; EVs; and internal combustion engines fueled with landfill gas-based methanol, CNG, LPG, and clean diesel results in decreases in fuel-cycle total energy consumption. Large decreases in energy use result from using FCVs, HEVs, and EVs. The decreases in energy use for CNG, LPG, and landfill gas-based methanol are caused mainly by the high conversion efficiencies during production of these fuels. The decreases in energy use for diesel, EVs, HEVs, and FCVs are caused by the high energy efficiencies of these vehicle technologies.

Figure 5 presents changes in fossil fuel consumption (by use) for each fuel or vehicle type. Fossil fuel consumption here includes consumption of petroleum, NG, and coal. With the exception of NG-based methanol, use of other fuels or vehicle types results in decreased fossil fuel consumption. The largest reductions in fossil fuel consumption occur when landfill gas-based methanol and herbaceous biomass-based ethanol are used, simply because of the non-fossil feedstocks used to produce these fuels. Use of HEVs, EVs, and corn-based ethanol reduces fossil fuel consumption only moderately. Note that use of woody biomass-based E100 helps achieve a greater-than-100% reduction in fossil fuel use; this is because the electricity credit produced from converting woody biomass to ethanol saves more fossil fuel than is used for other fuel-cycle activities.

## TABLE 10 Fuel-Cycle Energy Use and Emissions of a 2000 Model Year Car in 2005

| Vehicle Type | Energy Use (Btu/mi) | | | Emissions (all-location/in-basin for five criteria pollutants; g/mi) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total Energy | Fossil Energy | Petroleum | VOCs | CO | $NO_x$ | $PM_{10}$ | $SO_x$ | GHGs |
| **Gasoline Vehicles** | | | | | | | | | |
| Feedstock-related | 98 | 93 | 43 | 0.017/0.000 | 0.097/0.000 | 0.029/0.000 | 0.002/0.000 | 0.019/0.000 | 13 |
| Fuel-related | 874 | 860 | 63 | 0.059/0.021 | 0.061/0.011 | 0.114/0.020 | 0.015/0.002 | 0.092/0.007 | 60 |
| Vehicle operation | 3844 | 3844 | 3844 | 1.036/1.036 | 8.686/8.686 | 0.600/0.600 | 0.033/0.033 | 0.019/0.019 | 271 |
| Total | 4815 | 3949 | 3949 | 1.112/1.057 | 8.844/8.697 | 0.743/0.620 | 0.050/0.035 | 0.126/0.026 | 343 |
| **Diesel Vehicles** | | | | | | | | | |
| Feedstock-related | 89 | 85 | 39 | 0.016/0.000 | 0.008/0.000 | 0.026/0.000 | 0.002/0.000 | 0.014/0.000 | 12 |
| Fuel-related | 310 | 305 | 46 | 0.021/0.007 | 0.027/0.006 | 0.054/0.013 | 0.007/0.001 | 0.033/0.003 | 22 |
| Vehicle operation | 3494 | 3494 | 3494 | 0.384/0.384 | 1.100/1.100 | 1.092/1.092 | 0.121/0.121 | 0.079/0.079 | 280 |
| Total | 3893 | 3883 | 3580 | 0.421/0.391 | 1.215/1.106 | 1.173/1.105 | 0.129/0.122 | 0.126/0.082 | 313 |
| **CNG Vehicles** | | | | | | | | | |
| Feedstock-related | 336 | 337 | 7 | 0.020/0.001 | 0.080/0.002 | 0.120/0.006 | 0.003/0.000 | 0.012/0.000 | 32 |
| Fuel-related | 202 | 140 | 0 | 0.001/0.000 | 0.006/0.001 | 0.088/0.001 | 0.009/0.000 | 0.113/0.001 | 42 |
| Vehicle operation | 3844 | 3844 | 0 | 0.209/0.209 | 5.212/5.212 | 0.570/0.570 | 0.021/0.021 | 0.001/0.001 | 250 |
| Total | 4382 | 4318 | 7 | 0.229/0.210 | 5.297/5.215 | 0.778/0.578 | 0.033/0.021 | 0.126/0.002 | 324 |
| **M85 Vehicles: NG to Methanol** | | | | | | | | | |
| Feedstock-related | 262 | | 16 | 0.018/0.001 | 0.081/0.002 | 0.092/0.005 | 0.002/0.000 | 0.012/0.000 | 26 |
| Fuel-related | 1776 | 1771 | 97 | 0.099/0.021 | 0.170/0.021 | 0.415/0.049 | 0.014/0.002 | 0.031/0.004 | 79 |
| Vehicle operation | 3696 | 3696 | 958 | 0.595/0.595 | 7.383/7.383 | 0.570/0.570 | 0.022/0.022 | 0.007/0.007 | 258 |
| Total | 5736 | 5728 | 1071 | 0.712/0.616 | 7.643/7.405 | 1.077/0.624 | 0.039/0.024 | 0.050/0.010 | 362 |
| **M85 Vehicles: Landfill Gases to Methanol** | | | | | | | | | |
| Feedstock-related | 24 | 23 | 11 | 0.004/0.000 | 0.024/0.000 | 0.007/0.000 | 0.000/0.000 | 0.004/0.000 | 3 |
| Fuel-related | 532 | 529 | 16 | 0.004/0.001 | -0.257/-0.135 | 0.243/0.051 | -0.077/-0.046 | 0.182/-0.003 | -443 |
| Vehicle operation | 3696 | 958 | 958 | 0.595/0.595 | 7.383/7.383 | 0.570/0.570 | 0.022/0.022 | 0.007/0.007 | 258 |
| Total | 4252 | 1510 | 984 | 0.630/0.596 | 7.150/7.248 | 0.820/0.622 | -0.054/-0.024 | 0.193/0.004 | -182 |

**TABLE 10 (Cont.)**

| Vehicle Type | Energy Use (Btu/mi) | | | Emissions (all-location/in-basin for five criteria pollutants; g/mi) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total Energy | Fossil Energy | Petroleum | VOCs | CO | $NO_x$ | $PM_{10}$ | $SO_x$ | GHGs |
| **M100 Vehicles: NG to Methanol** | | | | | | | | | |
| Feedstock-related | 320 | 319 | 7 | 0.019/0.001 | 0.76/0.002 | 0.114/0.006 | 0.003/0.000 | 0.011/0.000 | 31 |
| Fuel-related | 2083 | 2081 | 109 | 0.112/0.021 | 0.206/0.024 | 0.517/0.059 | 0.013/0.002 | 0.011/0.003 | 85 |
| Vehicle operation | 3661 | 3661 | 0 | 0.548/0.548 | 6.949/6.949 | 0.540/0.540 | 0.021/0.021 | 0.003/0.003 | 254 |
| Total | 6064 | 6060 | 116 | 0.679/0.570 | 7.213/6.975 | 1.171/0.605 | 0.037/0.023 | 0.025/0.005 | 370 |
| **M100 Vehicles: Landfill Gases to Methanol** | | | | | | | | | |
| Feedstock-related | 0 | 0 | 0 | 0.000/0.000 | 0.000/0.000 | 0.000/0.000 | 0.000/0.000 | 0.000/0.000 | 0 |
| Fuel-related | 420 | 420 | 0 | -0.014/-0.006 | -0.364/-0.184 | 0.287/0.062 | -0.108/-0.062 | 0.213/-0.006 | -612 |
| Vehicle operation | 3661 | 0 | 0 | 0.548/0.548 | 6.949/6.949 | 0.540/0.540 | 0.021/0.021 | 0.003/0.003 | 254 |
| Total | 4081 | 420 | 0 | 0.534/0.542 | 6.585/6.767 | 0.827/0.602 | -0.087/0.003 | 0.216/-0.003 | -358 |
| **LPG Vehicles** | | | | | | | | | |
| Feedstock-related | 301 | 299 | 13 | 0.019/0.001 | 0.082/0.002 | 0.106/0.005 | 0.003/0.000 | 0.012/0.000 | 29 |
| Fuel-related | 238 | 235 | 74 | 0.027/0.009 | 0.034/0.009 | 0.082/0.021 | 0.005/0.002 | 0.012/0.001 | 17 |
| Vehicle operation | 3844 | 3844 | 577 | 0.256/0.256 | 6.080/6.080 | 0.570/0.570 | 0.021/0.021 | 0.000/0.000 | 268 |
| Total | 4382 | 4377 | 663 | 0.302/0.265 | 6.196/6.091 | 0.758/0.596 | 0.029/0.028 | 0.024/0.001 | 314 |
| **E85 Vehicles: Corn to Ethanol** | | | | | | | | | |
| Feedstock-related | 587 | 569 | 271 | 0.037/0.000 | 0.149/0.000 | 0.375/0.000 | 0.012/0.000 | 0.043/0.000 | 134 |
| Fuel-related | 1852 | 1804 | 79 | 0.082/0.017 | 0.397/0.016 | 0.400/0.031 | 0.143/0.002 | 0.540/0.003 | 76 |
| Vehicle operation | 3696 | 768 | 768 | 0.595/0.595 | 7.383/7.383 | 0.570/0.570 | 0.022/0.022 | 0.005/0.005 | 46 |
| Total | 6135 | 3142 | 1126 | 0.714/0.612 | 7.929/7.399 | 1.345/0.602 | 0.178/0.025 | 0.588/0.008 | 256 |
| **E85 Vehicles: Woody Biomass to Ethanol** | | | | | | | | | |
| Feedstock-related | 50 | 49 | 24 | 0.005/0.000 | 0.026/0.000 | 0.025/0.000 | 0.001/0.000 | 0.04/0.000 | 9 |
| Fuel-related | 2397 | 73 | 73 | 0.056/0.017 | 0.118/0.014 | 0.125/0.028 | 0.327/0.002 | -0.104/0.002 | -29 |
| Vehicle operation | 3694 | 768 | 768 | 0.595/0.595 | 7.383/7.383 | 0.570/0.570 | 0.022/0.022 | 0.005/0.005 | 46 |
| Total | 6143 | 890 | 870 | 0.657/0.611 | 7.528/7.398 | 0.722/0.598 | 0.350/0.024 | -0.095/0.007 | 26 |

**TABLE 10 (Cont.)**

| Vehicle Type | Energy Use (Btu/mi) Total Energy | Fossil Energy | Petroleum | Emissions (all-location/in-basin for five criteria pollutants; g/mi) VOCs | CO | $NO_x$ | $PM_{10}$ | $SO_x$ | GHGs |
|---|---|---|---|---|---|---|---|---|---|
| **E85 Vehicles: Herbaceous Biomass to Ethanol** | | | | | | | | | |
| Feedstock-related | 100 | 98 | 27 | 0.007/0.000 | 0.031/0.000 | 0.076/0.000 | 0.002/0.000 | 0.007/0.000 | 24 |
| Fuel-related | 1687 | 175 | 79 | 0.051/0.017 | 0.092/0.015 | 0.134/0.029 | 0.220/0.002 | -0.026/0.002 | 0 |
| Vehicle operation | 3696 | 768 | 768 | 0.595/0.595 | 7.383/7.383 | 0.570/0.570 | 0.022/0.022 | 0.005/0.005 | 46 |
| Total | 5483 | 1040 | 875 | 0.653/0.612 | 7.560/3.398 | 0.780/0.600 | 0.244/0.024 | -0.013/0.008 | 70 |
| **E100 Vehicles: Corn to Ethanol** | | | | | | | | | |
| Feedstock-related | 710 | 689 | 338 | 0.042/0.000 | 0.162/0.000 | 0.462/0.000 | 0.015/0.000 | 0.050/0.000 | 164 |
| Fuel-related | 2097 | 2041 | 84 | 0.088/0.016 | 0.481/0.018 | 0.471/0.034 | 1.176/0.002 | 0.653/0.002 | 81 |
| Vehicle operation | 3661 | 0 | 0 | 0.548/0.548 | 6.949/6.949 | 0.540/0.540 | 0.021/0.021 | 0.002/0.002 | -10 |
| Total | 6467 | 2730 | 422 | 0.679/0.564 | 7.592/6.967 | 1.473/0.574 | 1.212/0.023 | 0.704/0.004 | 234 |
| **E100 Vehicles: Woody Biomass to Ethanol** | | | | | | | | | |
| Feedstock-related | 38 | 38 | 19 | 0.002/0.000 | 0.009/0.000 | 0.024/0.000 | 0.001/0.000 | 0.001/0.000 | 8 |
| Fuel-related | 2779 | -124 | 84 | 0.056/0.016 | 0.132/0.015 | 0.128/0.030 | 0.405/0.002 | -0.153/0.000 | -51 |
| Vehicle operation | 3661 | 0 | 0 | 0.548/0.548 | 6.949/6.949 | 0.540/0.540 | 0.021/0.021 | 0.002/0.002 | -10 |
| Total | 6748 | -86 | 103 | 0./0.564 | 7.090/6.964 | 0.693/0.570 | 0.427/0.023 | -0.150/0.002 | -54 |
| **E100 Vehicles: Herbaceous Biomass to Ethanol** | | | | | | | | | |
| Feedstock-related | 101 | 99 | 23 | 0.005/0.000 | 0.015/0.000 | 0.088/0.001 | 0.002/0.000 | 0.005/0.000 | 27 |
| Fuel-related | 1891 | 4 | 84 | 0.049/0.016 | 0.099/0.016 | 0.139/0.031 | 0.272/0.002 | -0.055/0.001 | -15 |
| Vehicle operation | 3661 | 0 | 0 | 0.548/0.548 | 6.949/6.949 | 0.540/0.540 | 0.021/0.021 | 0.002/0.002 | -10 |
| Total | 5653 | 102 | 107 | 0.602/0.564 | 7.063/6.965 | 0.766/0.572 | 0.294/0.023 | -0.048/0.003 | 2 |
| **Electric Vehicles: U.S. Generation Mix** | | | | | | | | | |
| Feedstock-related | 120 | 107 | 24 | 0.012/0.000 | 0.034/0.001 | 0.057/0.001 | 0.007/0.000 | 0.037/0.000 | 31 |
| Fuel-related | 3471 | 2697 | 38 | 0.004/0.000 | 0.039/0.005 | 0.557/0.009 | 0.058/0.001 | 0.713/0.003 | 265 |
| Vehicle operation | 0 | 0 | 0 | 0.000/0.000 | 0.000/0.000 | 0.0000.000 | 0.021/0.021 | 0.000/0.000 | 0 |
| Total | 3590 | 2803 | 163 | 0.016/0.000 | 0.074/0.006 | 0.613/0.010 | 0.086/0.022 | 0.750/0.004 | 296 |

**TABLE 10 (Cont.)**

| Vehicle Type | Energy Use (Btu/mi) | | | Emissions (all-location/in-basin for five criteria pollutants; g/mi) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total Energy | Fossil Energy | Petroleum | VOCs | CO | $NO_x$ | $PM_{10}$ | $SO_x$ | GHGs |
| **Electric Vehicles: California Generation Mix** | | | | | | | | | |
| Feedstock-related | 156 | 138 | 13 | 0.010/0.000 | 0.037/0.001 | 0.053/0.002 | 0.004/0.000 | 0.017/0.000 | 22 |
| Fuel-related | 2838 | 2023 | 126 | 0.003/0.001 | 0.042/0.010 | 0.261/0.017 | 0.024/0.001 | 0.281/0.003 | 165 |
| Vehicle operation | 0 | 0 | 0 | 0.000/0.000 | 0.000/0.000 | 0.0000.000 | 0.021/0.021 | 0.000/0.000 | 0 |
| Total | 2994 | 2161 | 139 | 0.014/0.001 | 0.078/0.011 | 0.314/0.20 | 0.049/0.022 | 0.298/0.003 | 186 |
| **Electric Vehicles: Northeast U.S. Generation Mix** | | | | | | | | | |
| Feedstock-related | 157 | 134 | 21 | 0.015/0.000 | 0.033/0.001 | 0.052/0.002 | 0.006/0.000 | 0.030/0.001 | 27 |
| Fuel-related | 3445 | 2301 | 574 | 0.004/0.001 | 0.038/0.007 | 0.354/.015 | 0.037/.001 | 0.453/.014 | 210 |
| Vehicle operation | 0 | 0 | 0 | 0.000/0.000 | 0.000/0.000 | 0.0000.000 | 0.021/0.021 | 0.000/0.000 | 0 |
| Total | 3602 | 2444 | 595 | 0.019/0.01 | 0.071/0.08 | 0.406/0.017 | 0.063/0.022 | 0./0.015 | 237 |
| **Hybrid Electric Vehicles: U.S. Generation Mix** | | | | | | | | | |
| Feedstock-related | 95 | 87 | 28 | 0.012/.000 | 0.053/.000 | 0.039/0.001 | 0/0.000 | 0.024/0.000 | 20 |
| Fuel-related | 2054 | 1662 | 92 | 0.023/0.008 | 0/0.006 | 0/0.012 | 0/0.001 | 0/0.004 | 154 |
| Vehicle operation | 1403 | 1403 | 1403 | 0.266/0.266 | 2.172/2.172 | 0.300/0.300 | 0.026/0.026 | 0.007/0.007 | 101 |
| Total | 3552 | 3152 | 1523 | 0.301/0.273 | 2.266/2.178 | 0.659/0.313 | 0.064/0.027 | 0.421/0.011 | 275 |
| **Hybrid Electric Vehicles: West Coast Generation Mix** | | | | | | | | | |
| Feedstock-related | 114 | 102 | 22 | 0.012/0.000 | 0.054/0.001 | 0.036/0.001 | 0.002/0.000 | 0.012/0.000 | 15 |
| Fuel-related | 1738 | 1323 | 86 | 0.023/0.008 | 0.043/0.009 | 0.168/0.016 | 0.017/0.001 | 0.169/0.004 | 103 |
| Vehicle operation | 1403 | 1403 | 1403 | 0.266/0.266 | 2.172/2.172 | 0.300/0.300 | 0.026/0.026 | 0.007/0.007 | 101 |
| Total | 3254 | 2828 | 1511 | 0.300/0.274 | 2.269/2.181 | 0.504/0.317 | 0.045/0.027 | 0.187/0.011 | 219 |
| **Hybrid Electric Vehicles: Northeast U.S. Generation Mix** | | | | | | | | | |
| Feedstock-related | 114 | 100 | 26 | 0.014/0.000 | 0.052/0.000 | 0.036/0.001 | 0.003/0.000 | 0.020/0.000 | 18 |
| Fuel-related | 2041 | 1467 | 310 | 0.023/0.008 | 0.041/0.008 | 0.216/0.015 | 0.024/0.001 | 0.257/0.010 | 126 |
| Vehicle operation | 1403 | 1403 | 1403 | 0.266/0.266 | 2.172/2.172 | 0.300/0.300 | 0.026/0.026 | 0.007/0.007 | 101 |
| Total | 3558 | 2971 | 1739 | 0.303/0.274 | 2.264/2.180 | 0.552/0.316 | 0.053/0.027 | 0.283/0.017 | 245 |

**TABLE 10 (Cont.)**

| Vehicle Type | Energy Use (Btu/mi) | | | Emissions (all-location/in-basin for five criteria pollutants; g/mi) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total Energy | Fossil Energy | Petroleum | VOCs | CO | $NO_x$ | $PM_{10}$ | $SO_x$ | GHGs |
| **Hydrogen Fuel-Cell Vehicles: NG to Hydrogen** | | | | | | | | | |
| Feedstock-related | 168 | 167 | 4 | 0.010/0.000 | 0.040/0.001 | 0.060/0.003 | 0.001/0.000 | 0.006/0.000 | 16 |
| Fuel-related | 1829 | 1828 | 101 | 0.091/0.015 | 0.211/0.033 | 0.510/0.075 | 0.016/0.004 | 0.005/0.001 | 229 |
| Vehicle operation | 1922 | 1922 | 0 | 0.000/0.000 | 0.000/0.000 | 0.0000.000 | 0.021/0.021 | 0.000/0.000 | 0 |
| Total | 3919 | 3917 | 105 | 0.101/0.016 | 0.251/0.034 | 0.570/0.078 | 0.039/0.025 | 0.011/0.011 | 245 |
| **Methanol Fuel-Cell Vehicles: NG to Methanol** | | | | | | | | | |
| Feedstock-related | 218 | 217 | 5 | 0.013/0.001 | 0.052/0.002 | 0.078/0.004 | 0.002/0.000 | 0.008/0.000 | 21 |
| Fuel-related | 1420 | 1419 | 74 | 0.077/0.014 | 0.141/0.016 | 0.352/0.040 | 0.009/0.002 | 0.007/0.002 | 58 |
| Vehicle operation | 2496 | 2496 | 0 | 0.246/0.246 | 0.869/0.869 | 0.060/0.060 | 0.021/0.021 | 0.002/0.002 | 179 |
| Total | 4135 | 4132 | 79 | 0.336/0.261 | 1.061/0.887 | 0.490/0.104 | 0.032/0.023 | 0.017/0.004 | 258 |
| **Methanol Fuel-Cell Vehicles: Landfill Gases to Methanol** | | | | | | | | | |
| Feedstock-related | 0 | 0 | 0 | 0.000/0.000 | 0.000/0.000 | 0.000/0.000 | 0.000/0.000 | 0.000/.000 | 0 |
| Fuel-related | 287 | 287 | 0 | -0.01/-0.004 | -0.248/-.125 | 0.195/0.042 | -0.073/-.042 | 0.145/-0.004 | -418 |
| Vehicle operation | 2496 | 0 | 0 | 0.246/0.246 | 0.869/0.869 | 0.060/0.060 | 0.021/0.021 | 0.002/0.002 | 179 |
| Total | 2782 | 287 | 0 | 0.237/0.242 | 0.620/0.743 | 0.255/0.102 | -0.052/-.021 | 0.147/-0.003 | -238 |

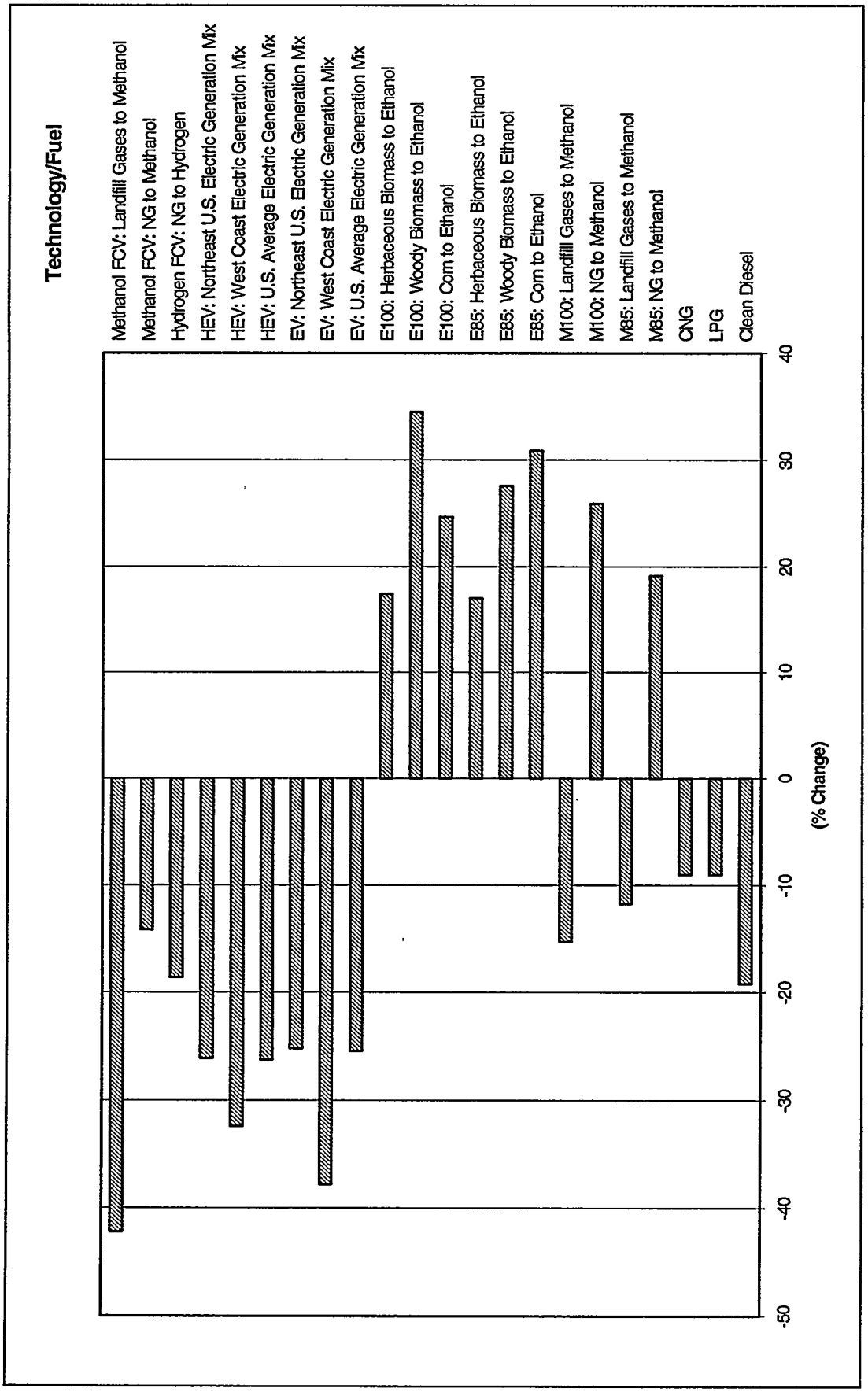
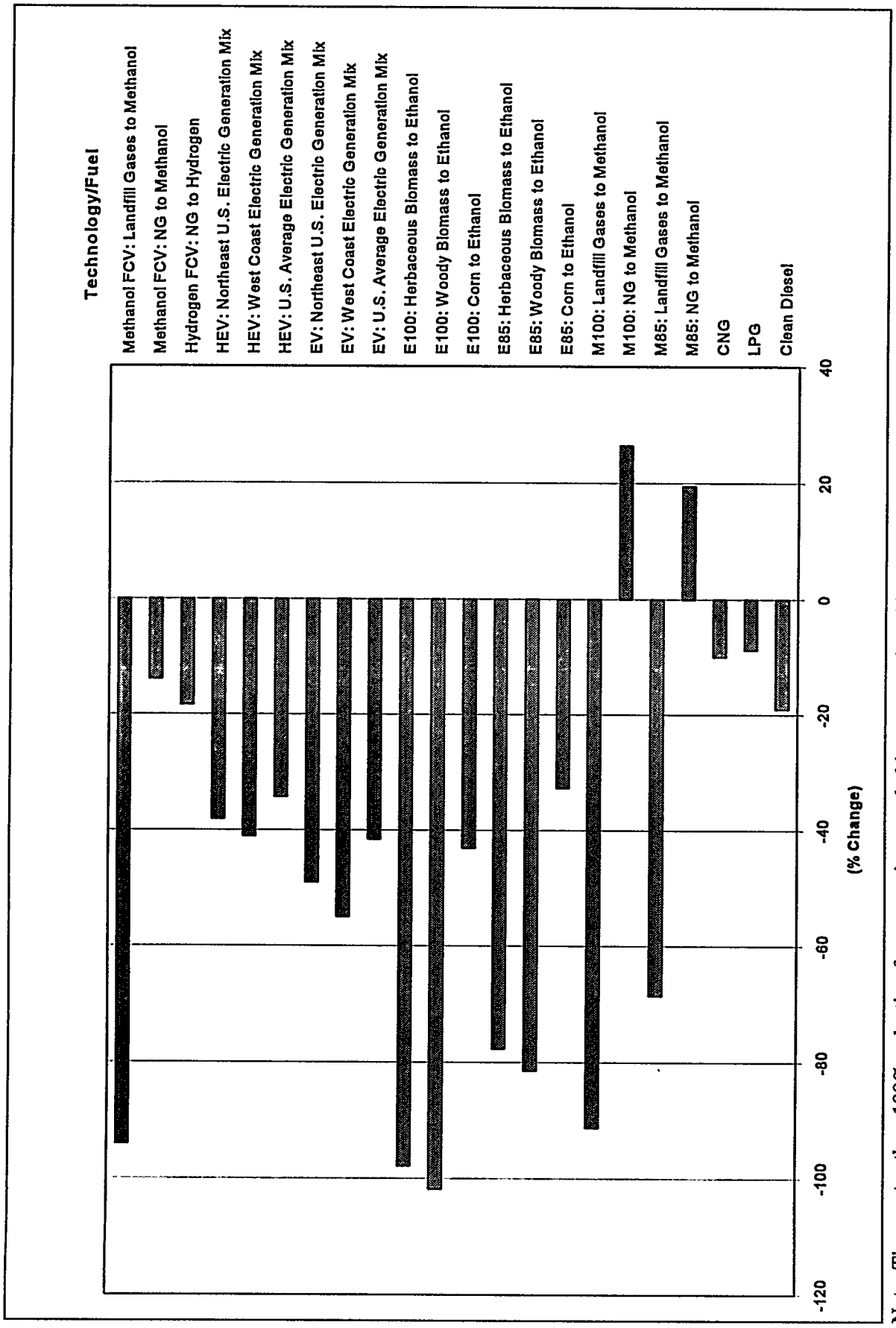



**FIGURE 4 Change in Fuel-Cycle Total Energy Use**




Note: The greater-than-100% reduction for converting woody biomass to ethanol is a result of fossil fuel savings from the electricity credit earned at ethanol plants.

**FIGURE 5 Change in Fuel-Cycle Fossil Fuel Use (relative to RFG)**

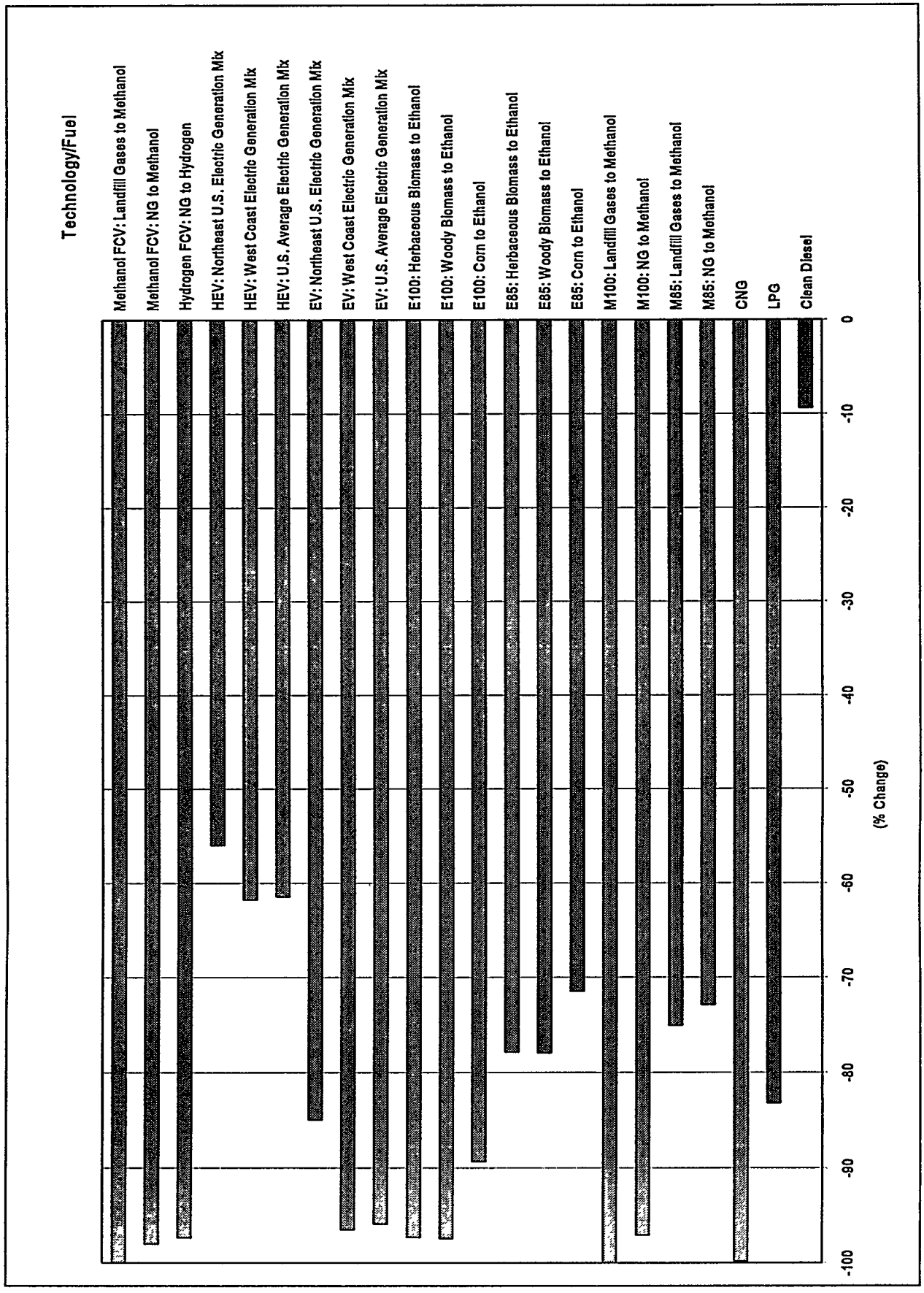



**FIGURE 6 Change in Fuel-Cycle Petroleum Use (relative to RFG)**

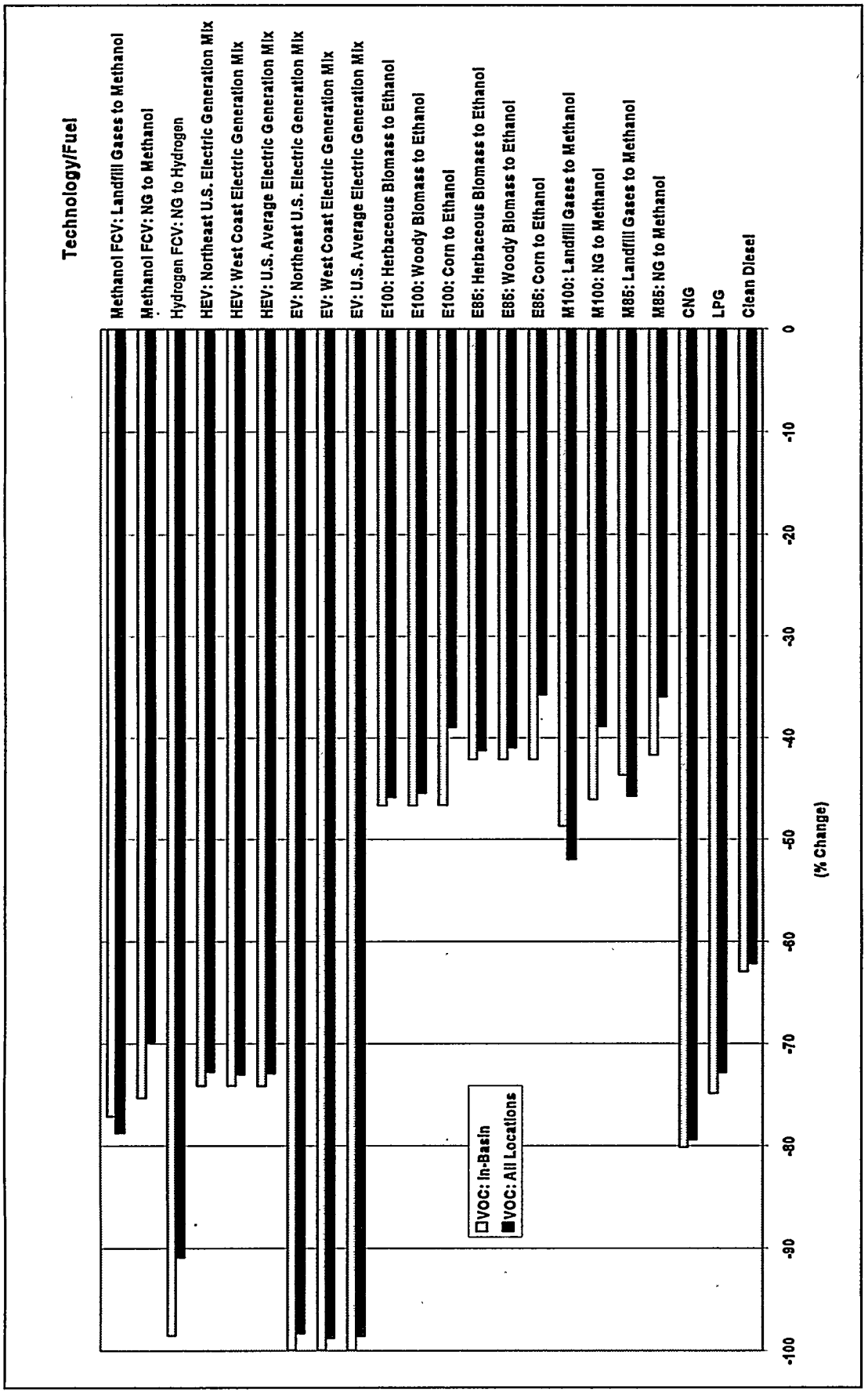



FIGURE 7 Change in Fuel-Cycle VOC Emissions (relative to RFG)

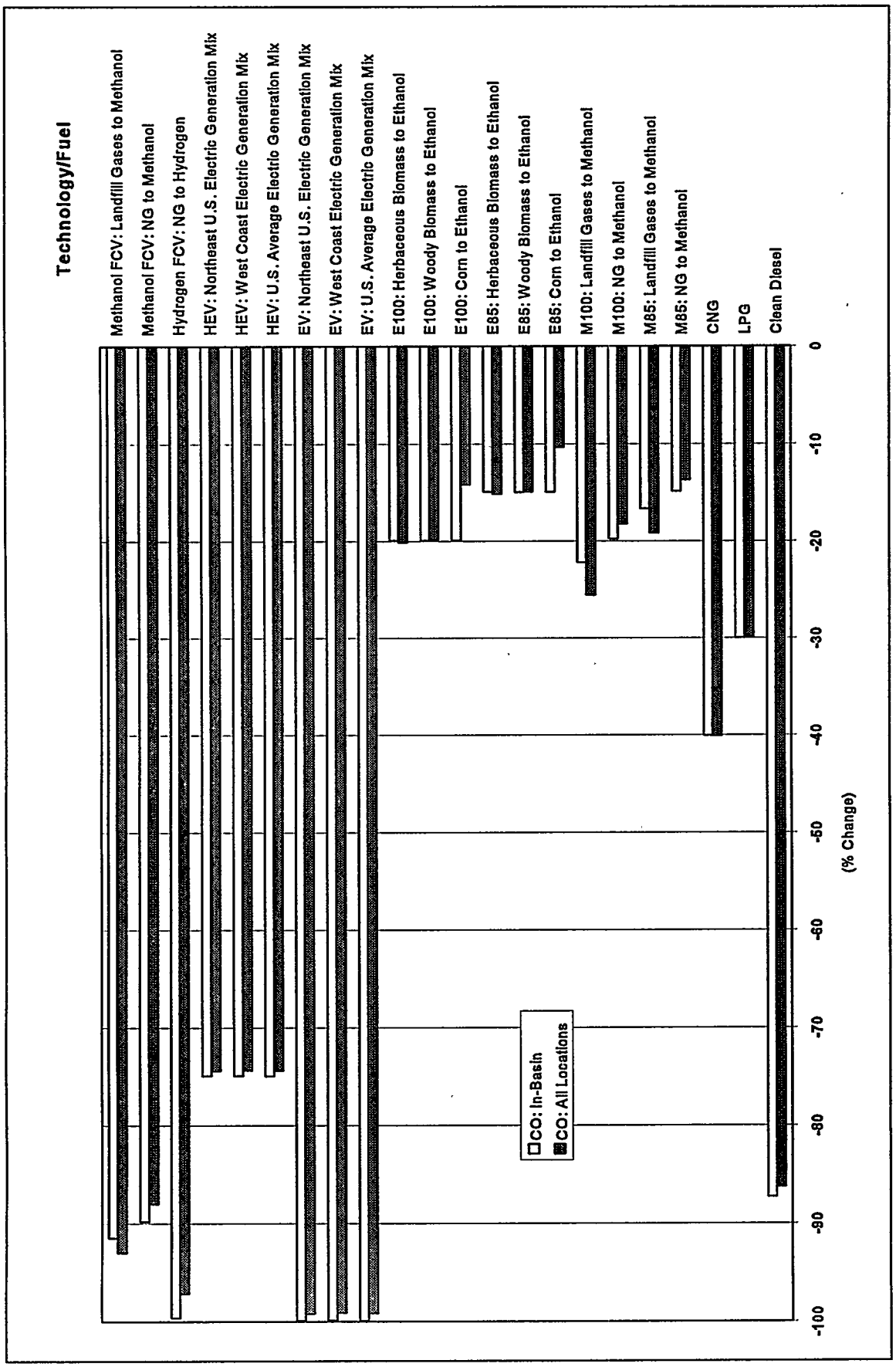



FIGURE 8 Change in Fuel-Cycle CO Emissions (relative to RFG)

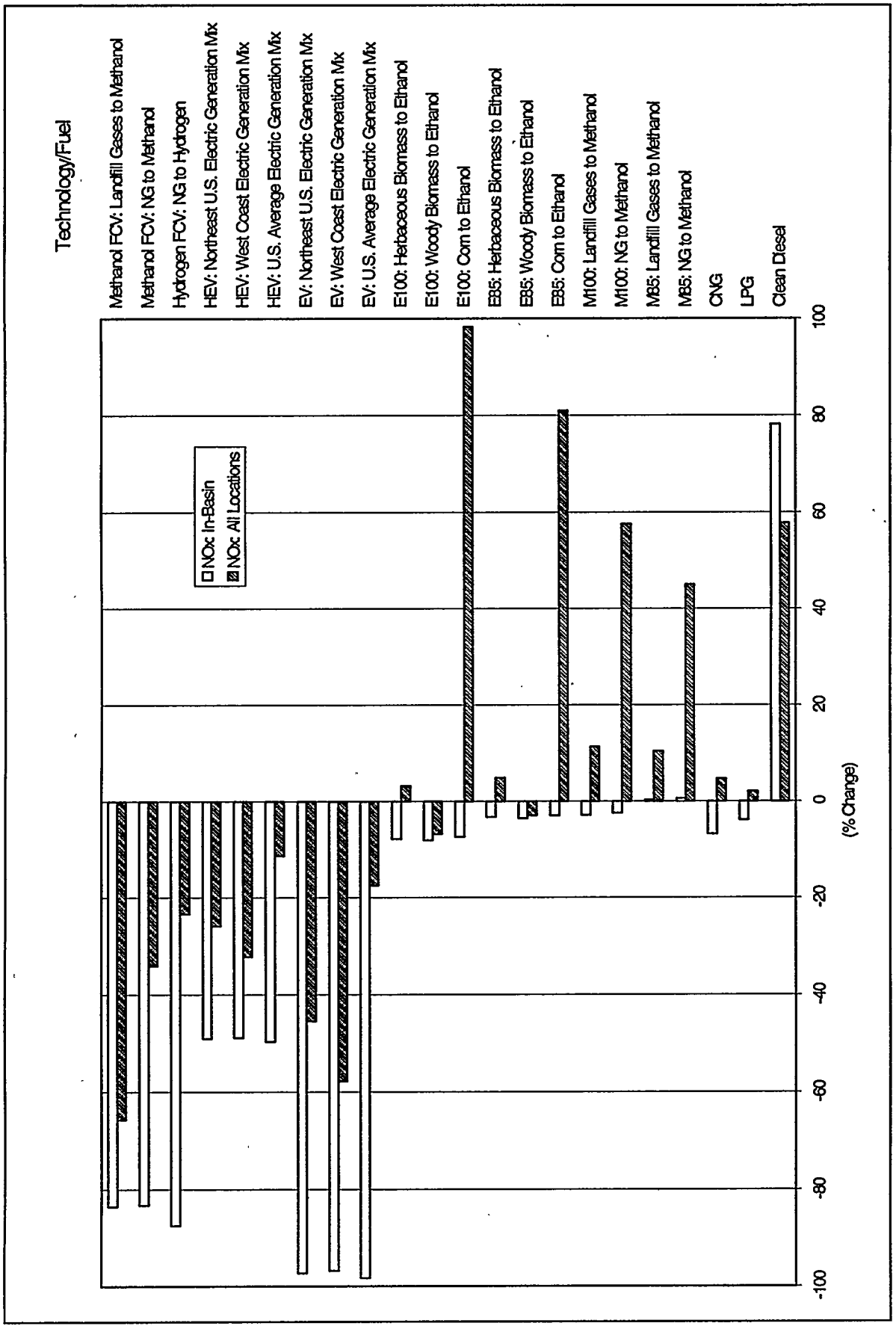
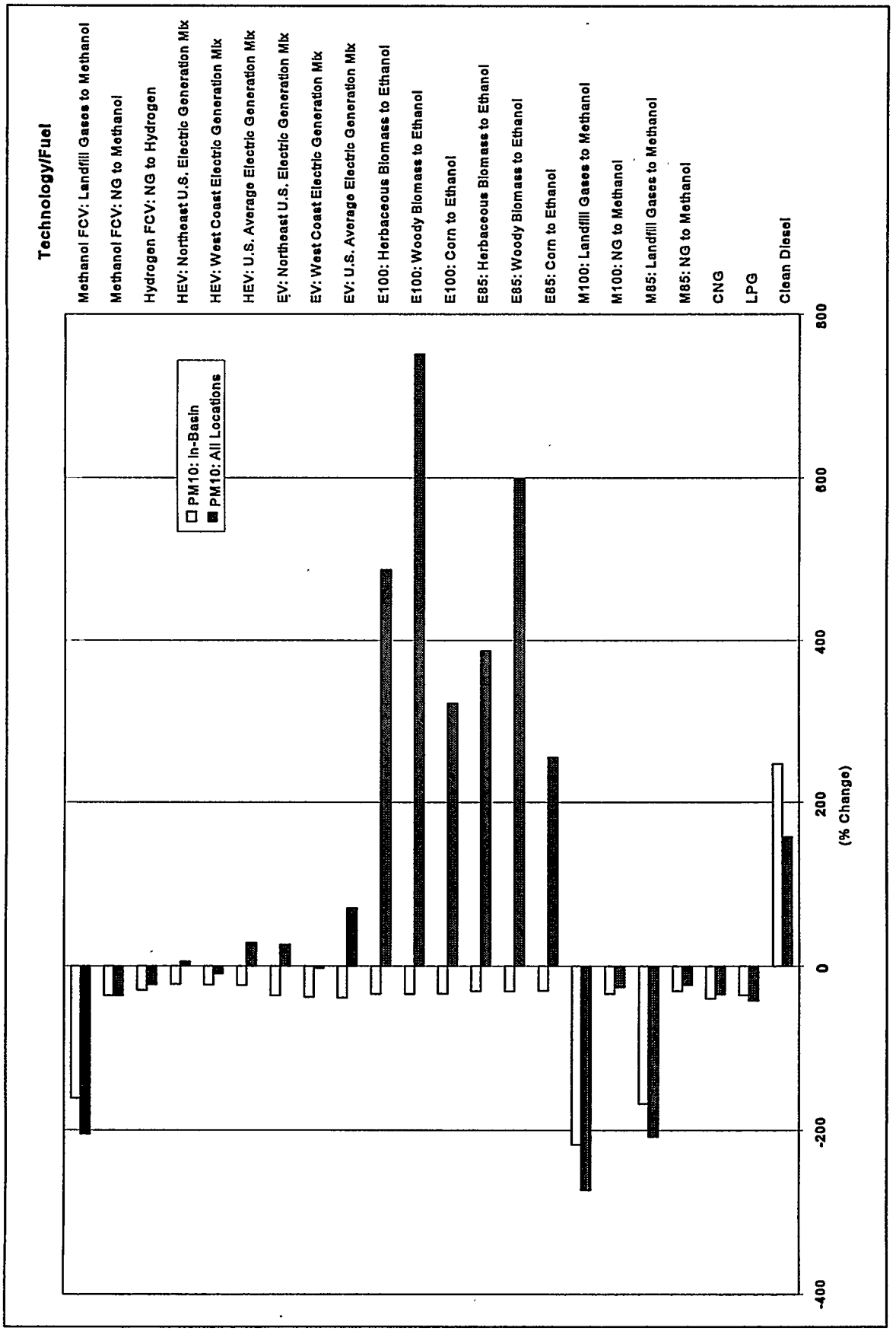
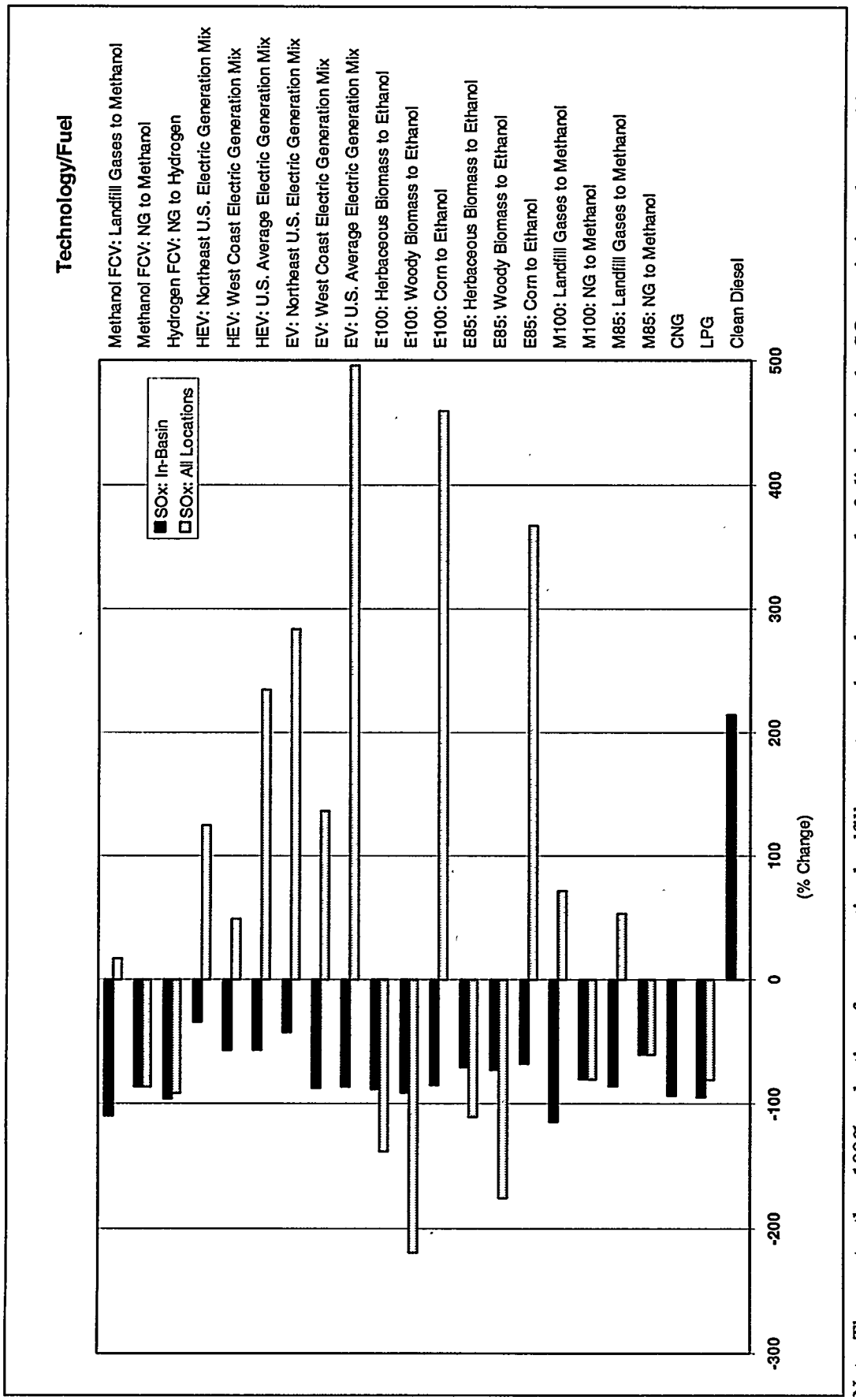



**FIGURE 9 Change in Fuel-Cycle $NO_x$ Emissions (relative to RFG)**



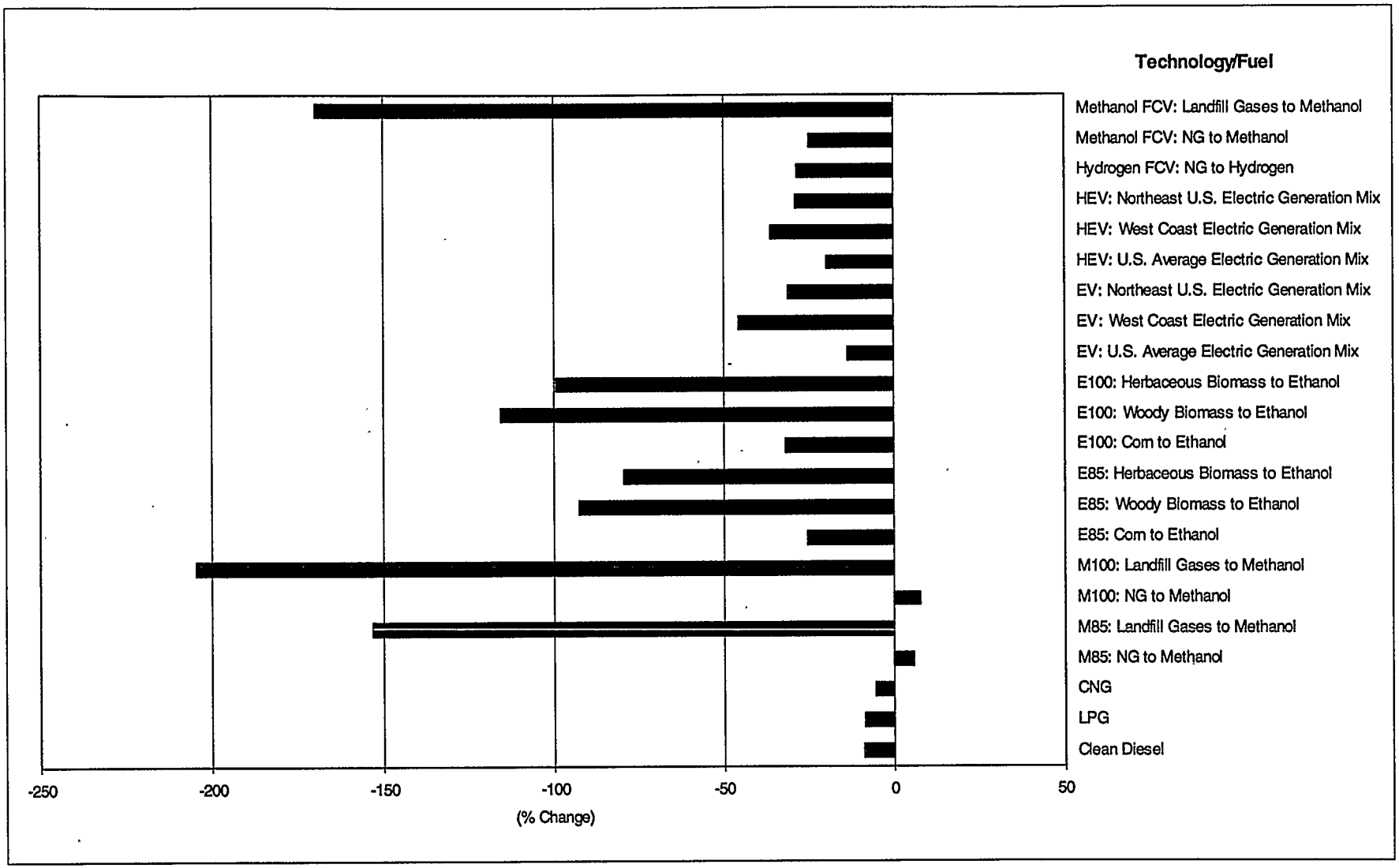

Note: The greater-than-100% reductions for converting landfill gases to methanol are a result of eliminating the $PM_{10}$ emissions that would otherwise be generated by burning landfill gases directly.

**FIGURE 10 Change in Fuel-Cycle $PM_{10}$ Emissions (relative to RFG)**




Note: The greater-than-100% reductions for converting landfill gases to methanol are a result of eliminating the $SO_x$ emissions that would otherwise be generated by burning landfill gases directly. The greater-than-100% reductions for converting biomass to ethanol are a result of the power plant $SO_x$ emissions eliminated by the electricity credit earned at ethanol plants.

**FIGURE 11 Change in Fuel-Cycle $SO_x$ Emissions (relative to RFG)**




Note: The greater-than-100% reductions for converting landfill gases to methanol are a result of eliminating the GHG emissions that would otherwise be generated by burning landfill gases directly, and those for biomass ethanol are caused by credits for the electricity produced at ethanol plants.

**FIGURE 12 Change in Fuel-Cycle Greenhouse Gas Emissions (relative to RFG)**

Figure 6 shows petroleum displacement by fuel and vehicle technology. Use of each fuel and vehicle type results in reductions in petroleum use compared with the baseline GV. Except for clean diesel, these fuels or vehicle technologies achieve large reductions in petroleum use. So, using these fuels or vehicle technologies is an effective way to reduce petroleum consumption by light-duty vehicles.

Figure 7 presents changes in both all-location and in-basin VOC emissions. Use of each fuel and vehicle technology helps reduce fuel-cycle VOC emissions in all locations and in metropolitan areas. Use of FCVs, HEVs, EVs, CNG, LPG, and clean diesel results in significant VOC emission reductions. Use of EVs and hydrogen FCVs almost eliminates VOC emissions. Ethanol and methanol use achieves moderate VOC emission reductions.

Figure 8 shows that use of the subject fuels or vehicle technologies helps reduce both all-location and in-basin fuel-cycle CO emissions. Hydrogen FCV and EV use almost eliminates CO emissions in all locations and in metropolitan areas. Use of methanol FCVs, HEVs, and clean diesel results in significant CO emission reductions. Use of ethanol, methanol, CNG, and LPG results in moderate CO emission reductions.

Figure 9 indicates that $NO_x$ emissions can decrease or increase, depending on the fuels or vehicle technologies used. Use of clean diesel causes increases in both all-location and in-basin $NO_x$ emissions. Use of herbaceous biomass-based and corn-based ethanol, methanol, CNG, and LPG causes increases in all-location $NO_x$ emissions, while use of these fuels helps reduce in-basin $NO_x$ emissions. $NO_x$ emission changes caused by using biomass-based ethanol, landfill gas-based methanol, CNG, and LPG are small. Use of FCVs, HEVs, and EVs helps reduce both all-location and in-basin $NO_x$ emissions; in-basin $NO_x$ emission reductions are higher than the all-location reductions.

Figure 10 shows a large variation in changes for fuel-cycle $PM_{10}$ emissions. Use of clean diesel causes an increase of about 200% in all-location or in-basin $PM_{10}$ emissions. Use of ethanol can increase all-location $PM_{10}$ emissions by two to seven times, but it still results in reductions in in-basin $PM_{10}$ emissions. The dramatic increases in all-location $PM_{10}$ emissions by using ethanol result from the large amount of $PM_{10}$ emissions generated during feedstock pretreatment and ethanol production at ethanol plants. Use of methanol, CNG, LPG, and hydrogen FCVs helps reduce both all-location and in-basin $PM_{10}$ emissions. Use of HEVs and EVs results in reductions of in-basin $PM_{10}$ emissions, but such use generally causes increases in all-location emissions. Use of landfill gas-based methanol results in reductions between 150% and 250%; these reductions are caused by significant $PM_{10}$ emissions that are generated from burning of landfill gases but are offset by methanol production.

Figure 11 shows that all-location $SO_x$ emissions are increased with the use of HEVs, EVs, and vehicles powered by corn-based ethanol and landfill gas-based methanol. However, use of these

fuels or vehicle types still results in decreased in-basin $SO_x$ emissions. Use of FCVs, biomass-based ethanol, NG-based methanol, CNG, and LPG reduces both all-location and in-basin $SO_x$ emissions. Use of clean diesel causes increases in in-basin $SO_x$ emissions but has little impact on all-location $SO_x$ emissions. $SO_x$ emission reductions caused by using biomass-based ethanol are a result of the electricity credit earned for biomass-ethanol plants. An $SO_x$ emission credit (from the electricity credit) is calculated from the amount of electricity generated and the average $SO_x$ emissions of the U.S. electric generation mix. Because of the $SO_x$ credit, using biomass-based ethanol results in a decrease in all-location $SO_x$ emissions of greater than 100%. Use of landfill gas-based methanol also results in a greater-than-100% reduction in in-basin $SO_x$ emissions; this is a result of the emission credit for converting landfill gas to ethanol, which prevents the $SO_x$ emissions that are otherwise produced from burning landfill gases.

Figure 12 shows changes in GHG emissions as GWP-weighted emissions of $CO_2$, $CH_4$, and $N_2O$. Except for use of NG-based methanol, where GHG emissions are slightly increased, use of all fuels and vehicle technologies helps reduce GHG emissions. The largest reductions occur for methanol produced from landfill gases. In fact, use of landfill gas-based methanol results in 150-200% reductions in GHG emissions. These reductions are caused by the $CO_2$ and $CH_4$ emission credits earned by converting the landfill gas to methanol — preventing emissions that would otherwise be produced from burning landfill gases directly. Large GHG emission reductions are achieved by using FCVs, HEVs, EVs, and ethanol. Emission reductions by these fuels or vehicle types are a result of more energy-efficient vehicles and/or use of renewable feedstocks for fuel production. Use of CNG, LPG, and clean diesel results in small GHG emission reductions.

The results presented in this section rely heavily on the assumptions made in the GREET model regarding the energy efficiencies of fuel-cycle stages, emission controls for combustion technologies, vehicle fuel economy and emission performance, ratio of in-basin and out-of-basin facilities, and many other factors. Changes in these assumptions will lead to different results in fuel-cycle emissions and energy use. However, the results presented here indicate general trends in relative emissions and energy uses for different fuels and vehicle types.