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. 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	225
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	280

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
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	163
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	233
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	266
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	264
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	189
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	206
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) 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
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

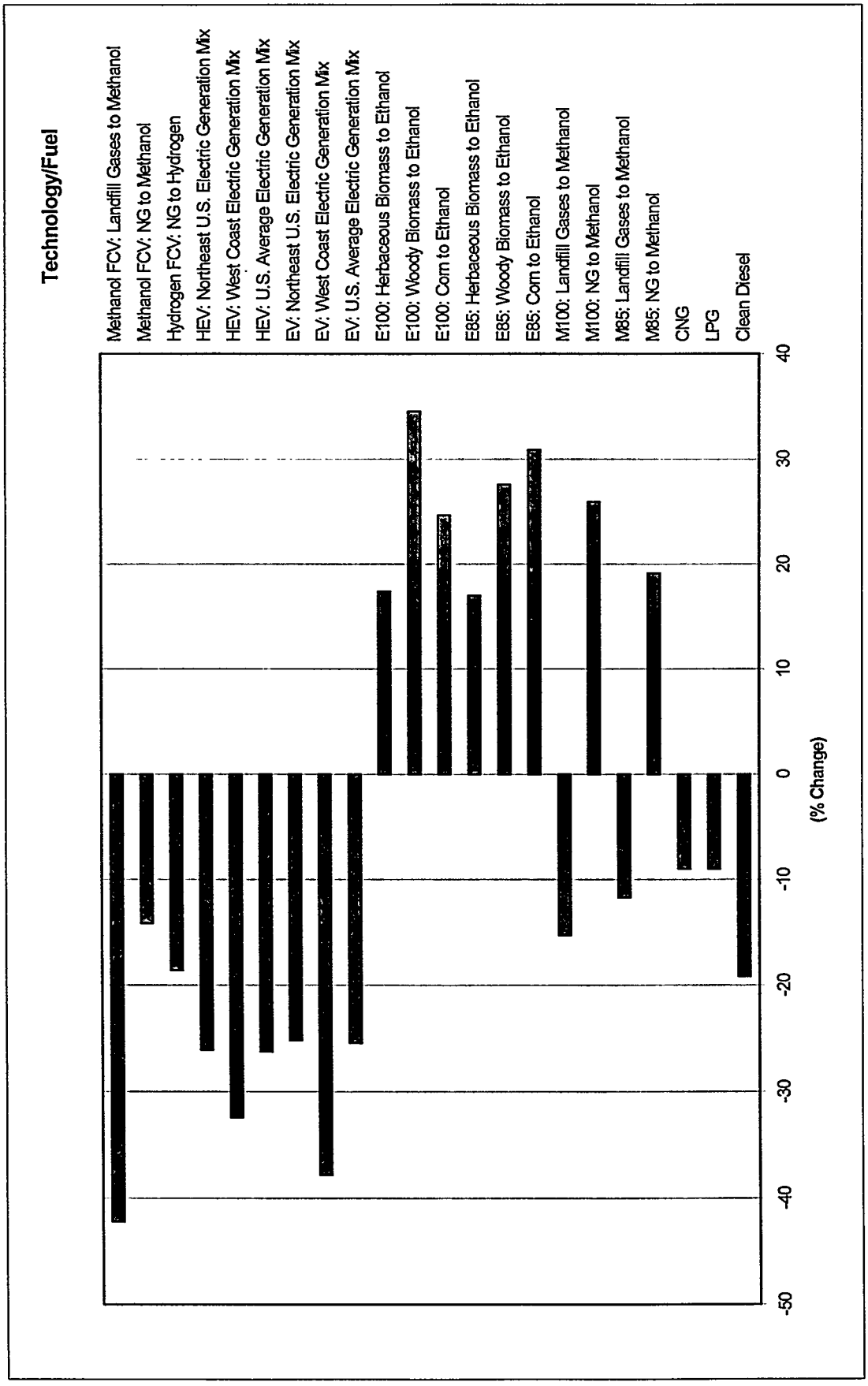
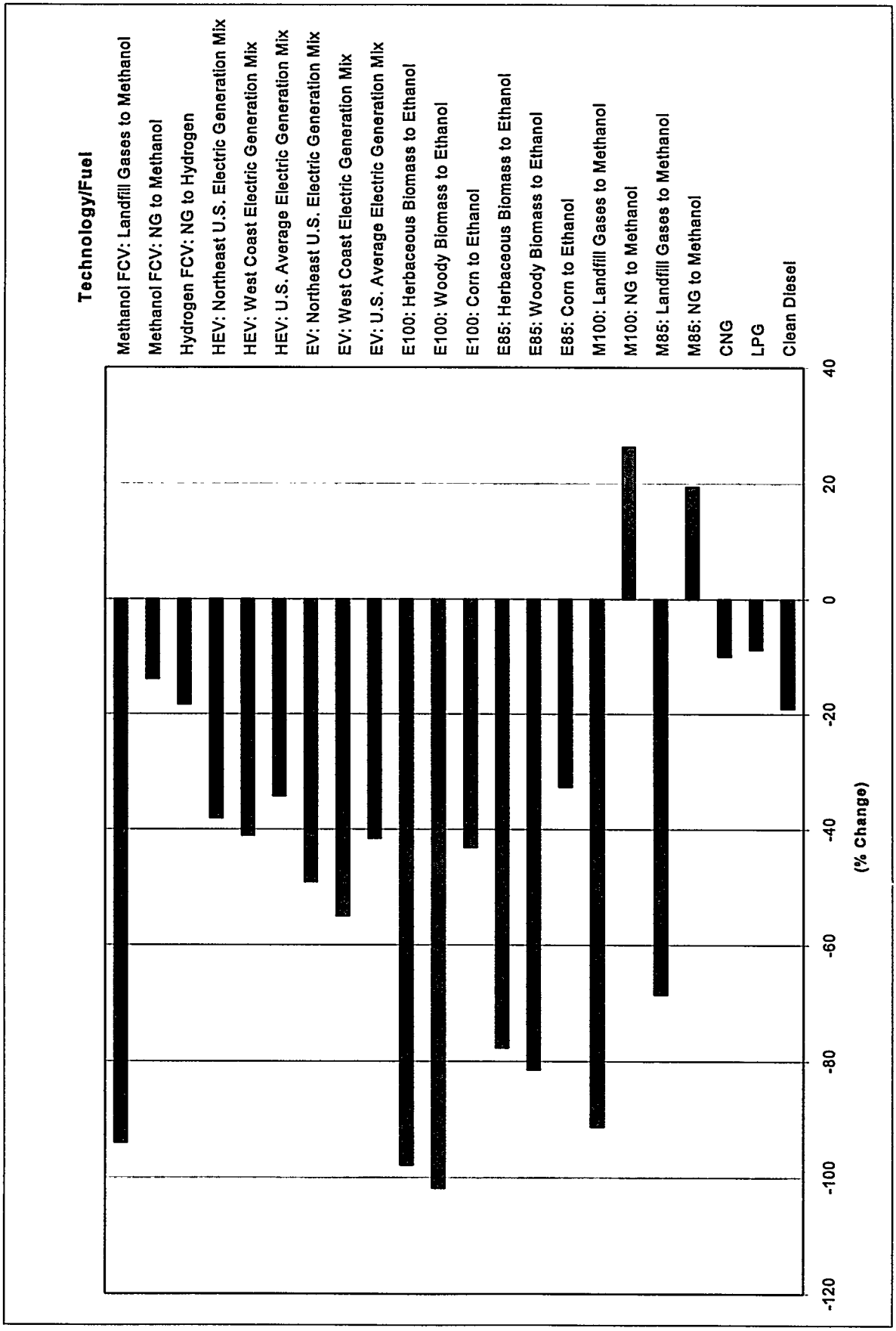


FIGURE 4 Change in Fuel-Cycle Total Energy Use



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)

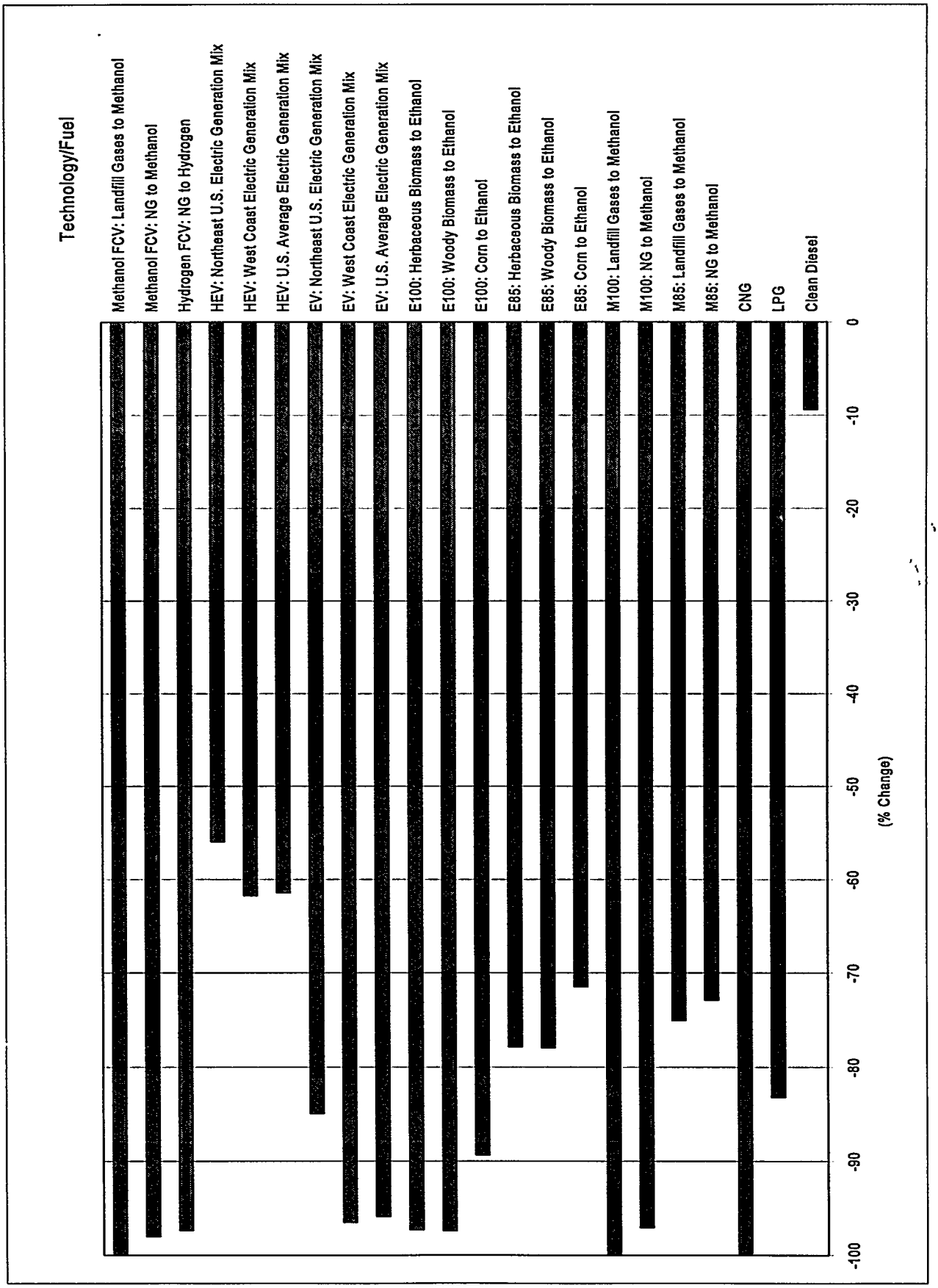


FIGURE 6 Change in Fuel-Cycle Petroleum Use (relative to RFG)

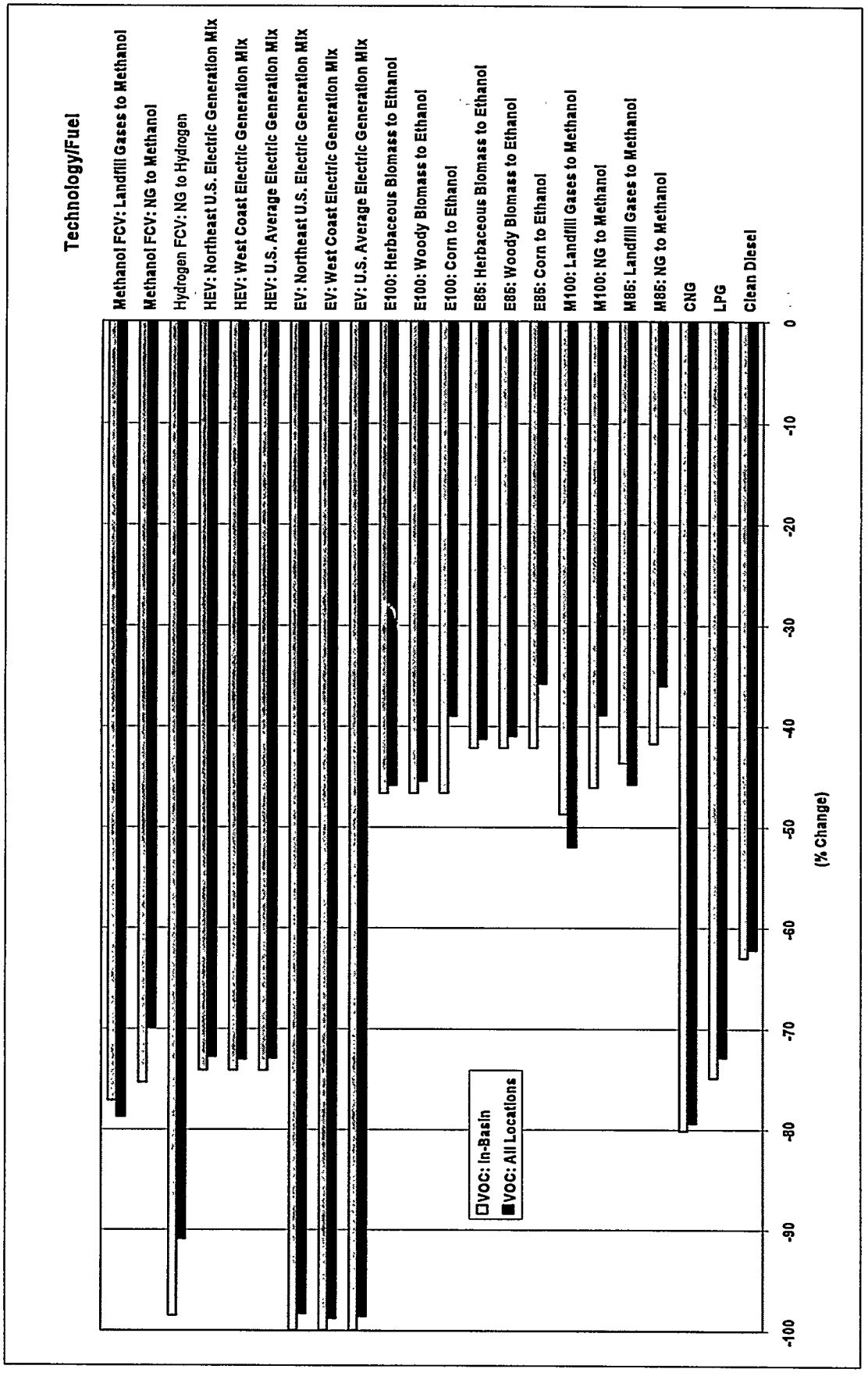


FIGURE 7 Change in Fuel-Cycle VOC Emissions (relative to RFG)

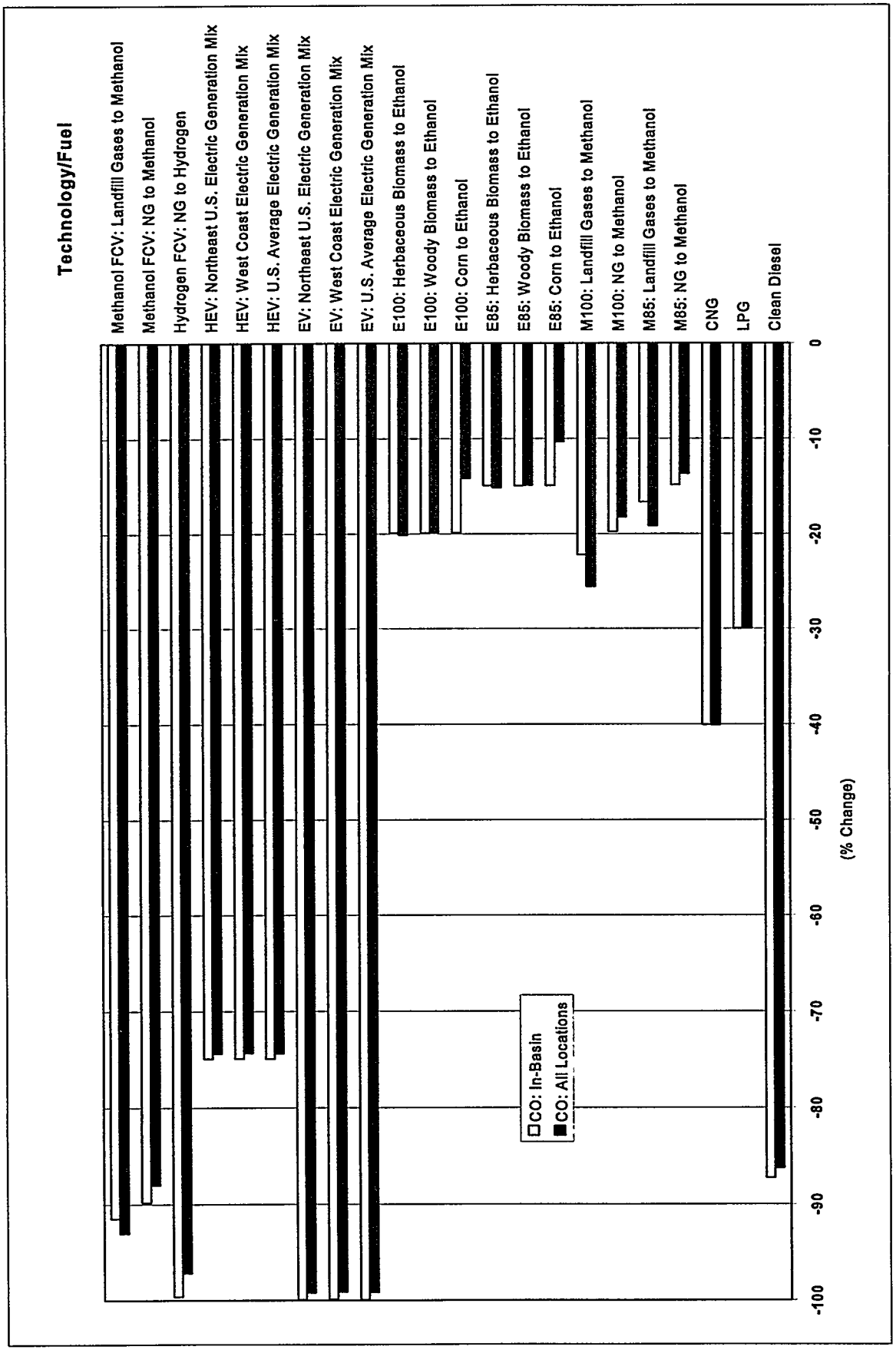


FIGURE 8 Change in Fuel-Cycle CO Emissions (relative to RFG)

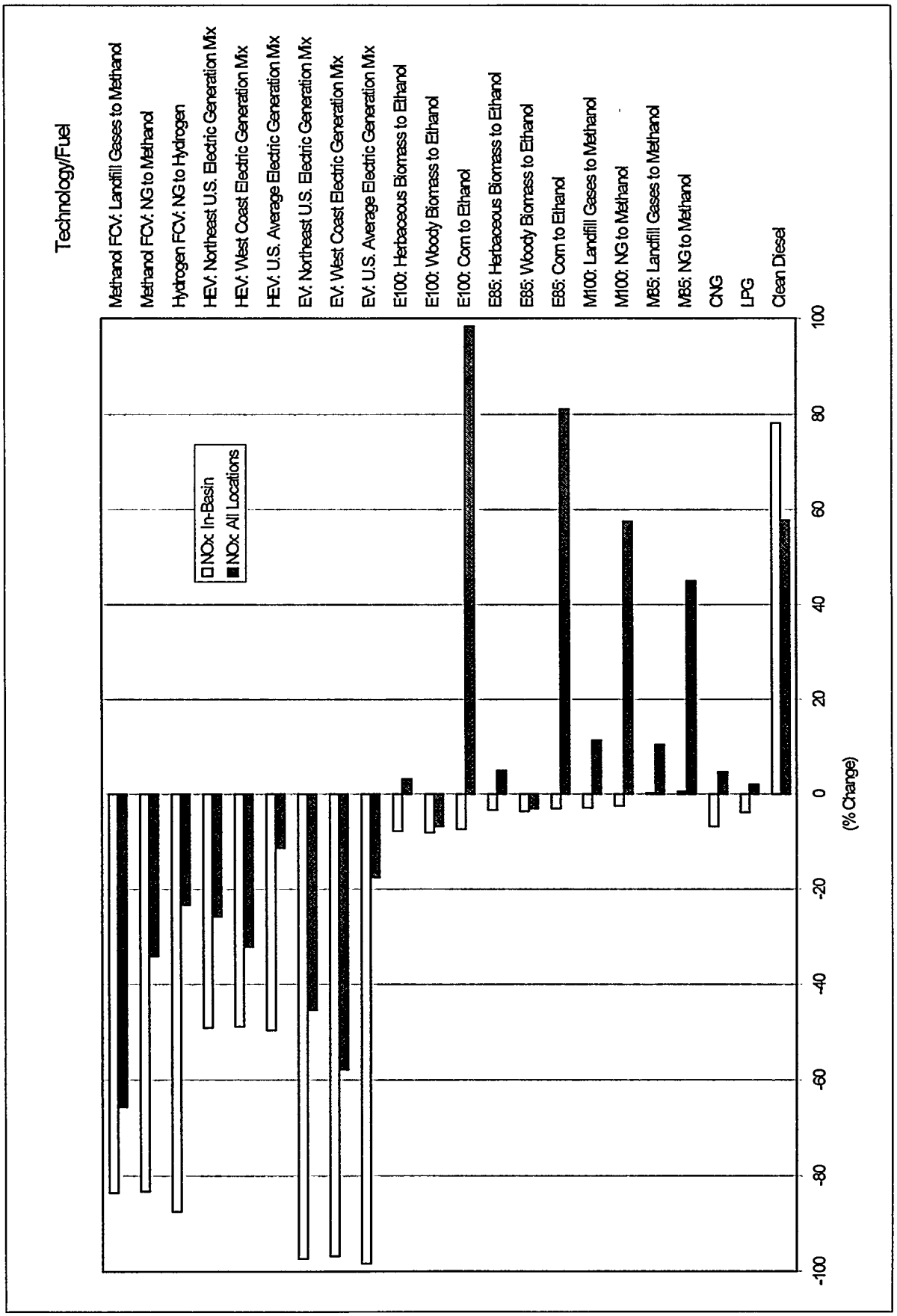
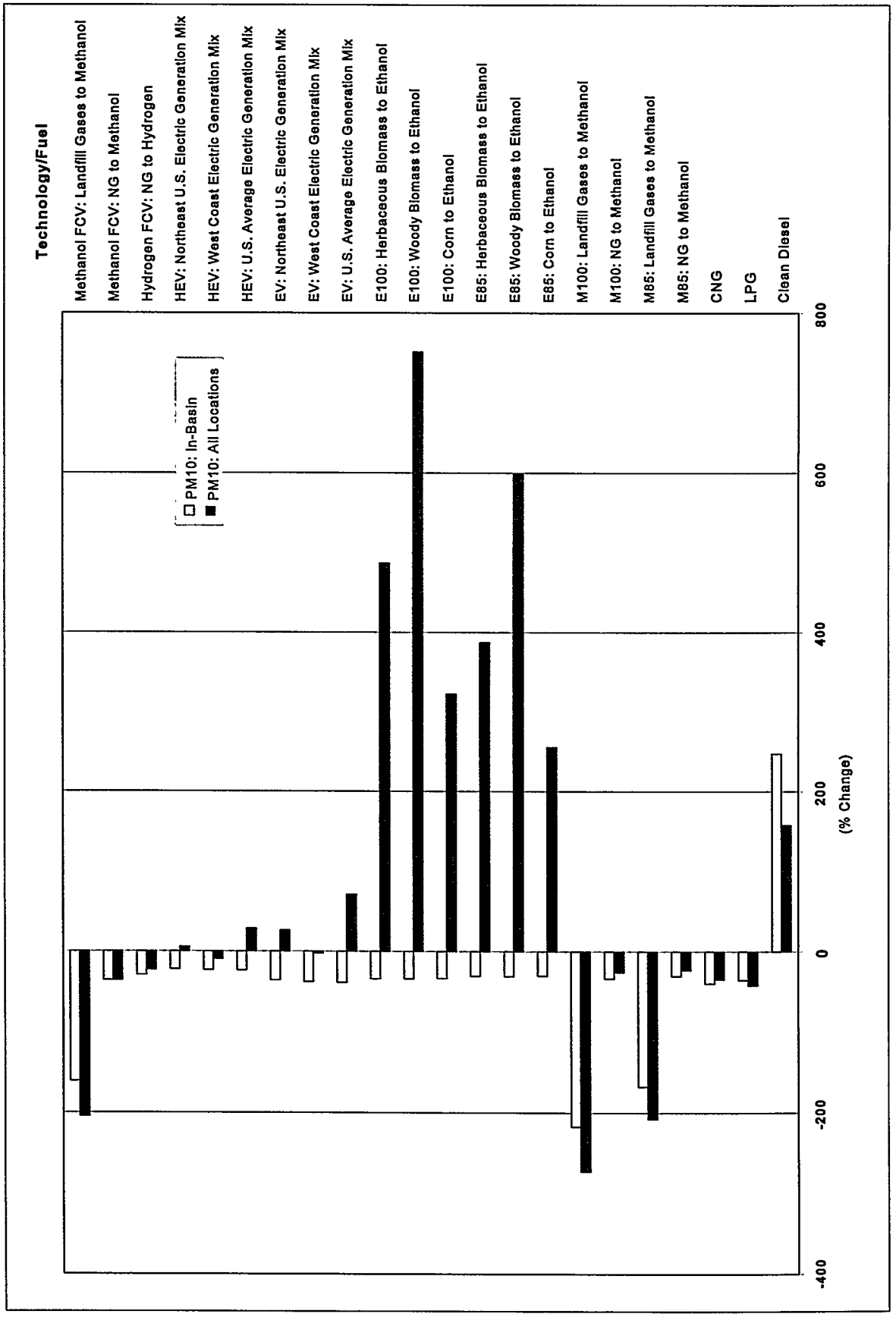
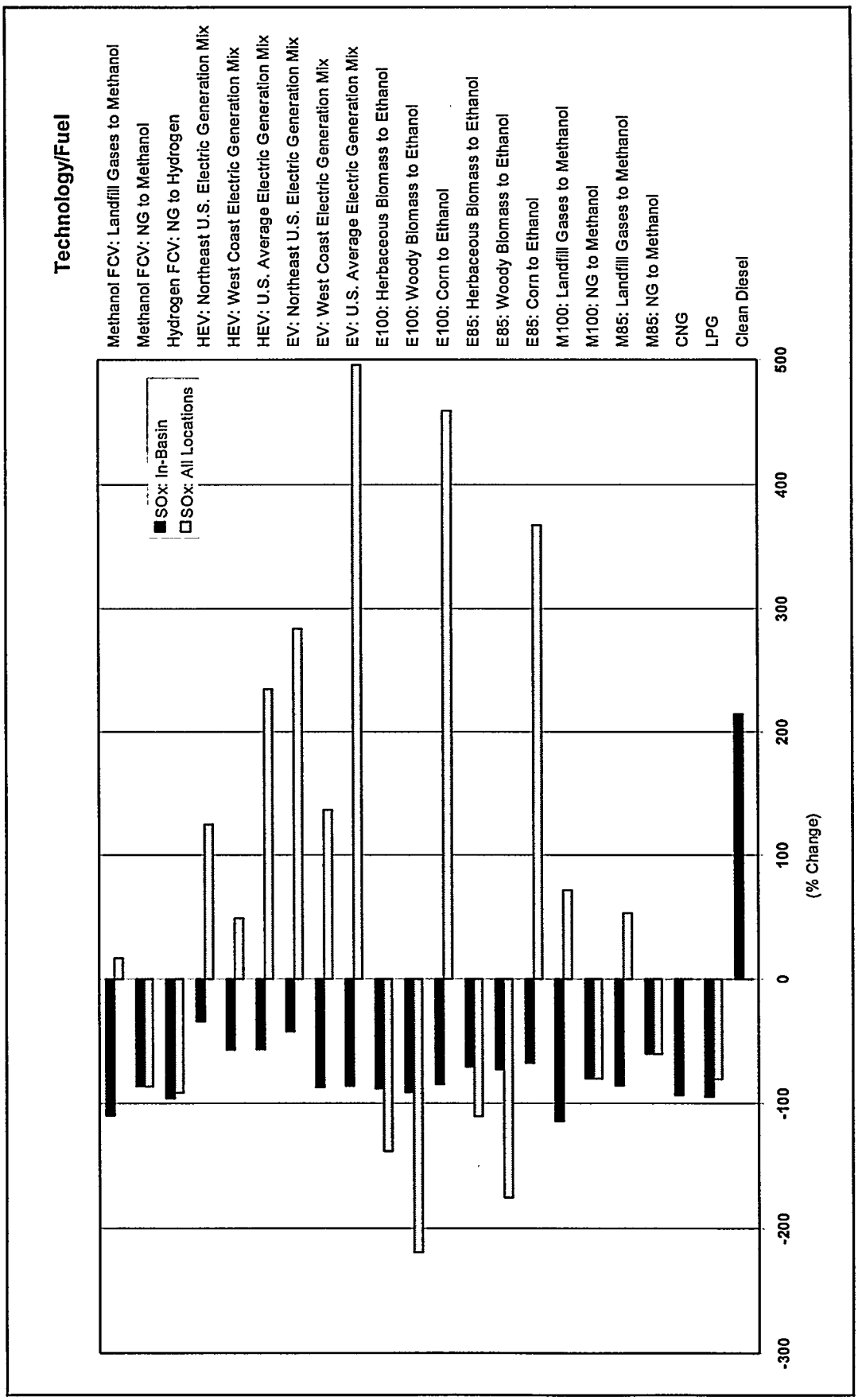


FIGURE 9 Change in Fuel-Cycle NO_x Emissions (relative to RFG)



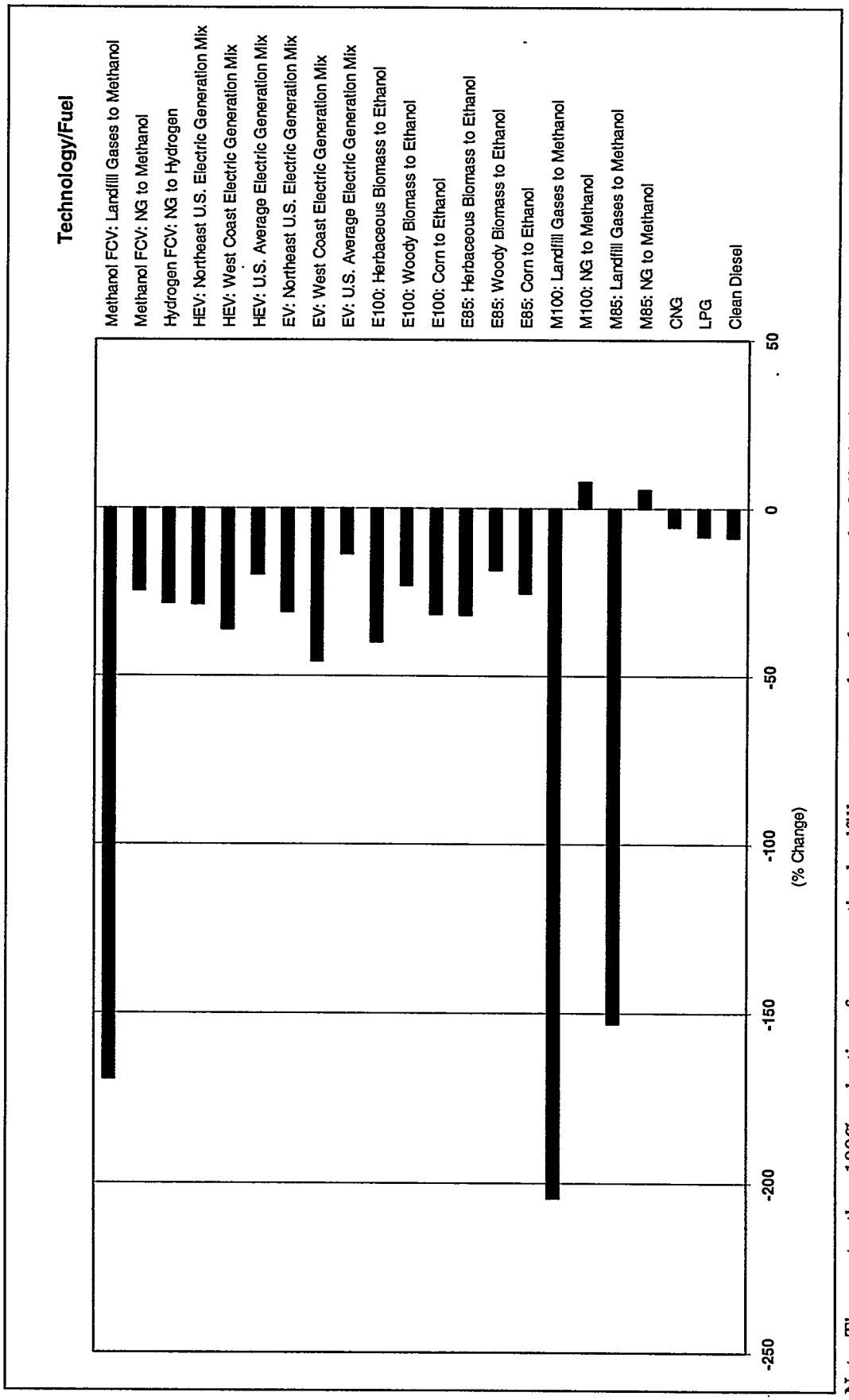
Note: The greater-than-100% reductions for converting landfill gases to methanol are a result of eliminating the PM_{10} emissions that would otherwise be generated by burning landfill gases directly.

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.

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.