Section 5
Conclusions

In this study, 11 fuels (RFG, RFD, DME, methanol, ethanol, LPG, CNG, LNG, F-T50, B20, and hydrogen) that are candidates for use in 3X vehicles were evaluated in three power system applications (SIDI engine, CIDI engine, or fuel cell) for a total of 13 propulsion system/fuel combinations. Two scenarios depicting alternative levels of 3X market penetration of light-duty-vehicle sales were developed and used to estimate the fuel production and distribution infrastructure needed to satisfy the fuel demands of 3X vehicles and the fuel-cycle energy and emissions impacts of the 13 potential propulsion system/fuel combinations. Capital needs and impacts were generated for each year from market introduction (2007 in the high-market-share scenario and 2013 in the low-market-share scenario) to 2030 for each of the propulsion system/fuel combinations.

As expected, cumulative capital needs were found to vary by technology and scenario. Of particular interest, though, is that supplying the low-market-share scenario's gasoline-equivalent demand requires capital investment of less than $50 billion for all fuels except hydrogen, which is estimated to require a total cumulative investment of $128–146 billion. By contrast, production and distribution facilities with gasoline-equivalent capacity of 1.6 MMBD (which is equivalent to 3X fuel demand in the high-market-share scenario) requires cumulative capital investments of $51 billion for LNG, $88 billion for ethanol, $101 billion for methanol, $123–164 billion for CNG, $162 billion for DME, and $478–559 billion for hydrogen. Although these substantial capital requirements are spread over many years, their sheer magnitude could pose a challenge to the widespread introduction of 3X vehicles.

Petroleum displacement will occur if substantial numbers of 3X vehicles enter the fleet, and adverse impacts on refineries are inevitable. However, the commitment of time and resources to 3X technology development should provide ample economic signals and sufficient lead time for refinery operators to adjust their business to accommodate different fuel demands, including, perhaps, lower gasoline demand. Such an economic restructuring would be considerably less severe than the industry consolidations that occurred during the 1970s and 1980s.

Energy and emissions impacts of 3X vehicles are highly dependent on market penetration and thus differ dramatically between the two scenarios examined in this study. Because impacts are relatively small under the low-market-share scenario, most of the discussion presented here focused on the more significant results obtained for the high-market-share scenario. For all 3X propulsion system/fuel technologies, total energy and fossil fuel use by U.S. light-duty vehicles decline significantly under the high-market-share scenario relative to reference scenario estimates for 2030. Fuel savings occur as a result of fuel-efficiency improvements, which apply to all 3X technologies and reduce LDV energy use by more than 25%, as well as a result of fuel substitution, which applies to the nonpetroleum-fueled alternatives studied. Together, the two effects reduce LDV petroleum use in 2030 by as much as 45% relative to the reference scenario. GHG emissions follow a similar pattern. Total GHG emissions decline by 25–30% with most of the propulsion system/fuel alternatives. For those using renewable fuels (i.e., ethanol from biomass and hydrogen from solar energy), GHG emissions drop by 33% (hydrogen) and 45% (ethanol) relative to the level estimated for the reference scenario.

Among the five criteria pollutants, urban NO_x emissions decline slightly for 3X vehicles using CIDI and SIDI engines and drop substantially for fuel-cell vehicles (FCVs). Urban CO emissions decline for CIDI and FCV alternatives, while VOC emissions drop significantly for all alternatives except RFG-, MeOH- and EtOH-fueled SIDI engines. With the exception of CIDI engines using RFD, F-T50, or B20 (which increase urban PM_{10} emissions by over 30% in the high scenario), all propulsion system/fuel alternatives reduce urban PM_{10} emissions. Reductions are approximately 15–20% for fuel cells and methanol ethanol-, CNG-, or LPG-fueled SIDI engines (RFG- and LNG-fueled SIDI engines and DME-fueled CIDI engines have only very slight reductions). Although urban SO_x emissions declined for all of the alternatives, SO_x emissions resulting from the use of LNG were higher than those resulting from the use of hydrogen, LPG, and CNG.

Table 5.1 qualitatively summarizes impacts of the 13 alternatives on capital requirements and on energy use and emissions relative to the reference scenario. The table clearly shows the trade-off between costs and benefits. For example, while hydrogen FCVs have the greatest incremental capital needs, they offer the largest energy and emissions benefits. On the basis of the cost and benefit changes shown, methanol and gasoline FCVs appear to have particularly promising benefits-to-costs ratios. As stated in the beginning of this report, all 3X technologies were assumed to become an engineering reality. This is speculative, particularly for some less mature technologies, such as fuel cells and DME fuel. By its very nature, the assumption of technological readiness should be a subject of continued reexamination.

The air quality implications of these emissions results should be interpreted cautiously. Changes in emissions of the five criteria pollutants (as presented in Table 5.1) do not necessarily translate into similar changes in air quality, simply because emissions from different fuels and upstream fuel-production activities occur in different locations and at different times and are dependent on atmospheric processes. Generally speaking, upstream emissions occur outside urban areas, while vehicular emissions occur within urban areas. Because of high population exposure (especially where mortality effects exist), emissions in urban areas generate far greater damage than those outside urban areas. That is why urban emissions have been estimated in this analysis. However, as discussed in Section 4.3.3, those estimates are based on broad, categorical data that may not be representative of all urban areas and that do not take into account the effects of varying local climatic conditions. Moreover, because methanol, DME, and much of LPG were assumed to be produced in foreign countries, some of the emissions from their production are not included in the estimates shown here.

Table 5.1 Impacts of Propulsion System/Fuel Alternatives for 3X Vehicles Relative to the Reference Scenario

Parameter	RFG[a]	MeOH[a]	EtOH[a]	LPG[a]	CNG[a]	LNG[a]	RFD[a]	DME[a]	F-T50[a]	B20[a]	GFCV[a]	MFCV[a]	HFCV[a]
Cost of fuel production	0[b]	--	--	-	-	-	0	---	-	0	0	--	---
Cost of fuel distribution	0	-	-	-	---	-	0	-	0	0	0	-	---
Total energy use	+++	++	+	+++	+++	+++	+++	++	++	+++	+++	++	+
Fossil energy use	++	++	+++	++	++	++	++	++	++	++	++	++	+++
Petroleum use	+	+++	+++	++	+++	+++	+	+++	++	+	+	+++	+++
GHG emissions	++	++	+++	++	++	++	++	++	++	++	++	++	+++
VOC emissions[c]	0	0	0	+	+	+	+	+	+	+	++	+++	+++
CO emissions[c]	0	0	0	0	0	0	++	++	++	++	+++	+++	+++
NO_x emissions[c]	0	0	0	0	0	0	0	0	0	0	+++	+++	+++
PM_{10} emissions[c]	0	++	++	++	++	0	---	0	---	---	++	++	++
SO_x emissions[c]	+	+++	+++	+++	+++	+	+	+++	++	+	+	+++	+++

[a] RFG: reformulated gasoline
MeOH: methanol
EtOH: ethanol
LPG: liquefied petroleum gas
CNG: compressed natural gas
LNG: liquefied natural gas
RFD: *reformulated diesel*
DME: dimethyl ether
F-T50: 50% Fischer-Tropsch diesel and 50% conventional diesel
HFCV: hydrogen fuel-cell vehicles
B20: 20% biodiesel and 80% conventional diesel
GFCV: gasoline fuel-cell vehicles
MFCV: methanol fuel-cell vehicles

[b] Key:
0: no change
-: a little worse
--: worse
---: worst
+: a little better
++: better
+++: best

[c] Urban emissions

As shown in Table 5.1, urban PM_{10} emissions from ethanol-fueled 3X vehicles are less than those from most of the alternatives examined. In marked contrast, the Phase 1 results did not disaggregate criteria emissions into urban and nonurban components. PM_{10} emissions from ethanol occur largely upstream (from farming and ethanol production) and outside urban areas, while PM_{10} emissions from the diesel-like fuels (RFD, F-T50 and B20) occur during vehicle operation, most of which is inside urban areas. Beyond the qualitative comparison of totals shown in Table 5.1, increased urban PM_{10} emissions from RFD and, to a lesser extent, from F-T50 and B20 may also produce worse health effects because diesel PM_{10} emissions, much of which is fine particulate matter of 2.5 μm or less ($PM_{2.5}$), may have much greater damage per unit than ethanol PM_{10} emissions, which tend to be in the 2.5–10 μm range and to be removed from urban populations. Full assessment of the damage caused by emissions from each fuel requires air quality modeling and risk assessment beyond the scope of this analysis.

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