Alcohol Fuel Flexibility – Progress and Prospects

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Introduction

Alcohol flexible fuel vehicles (FFVs) represent a mature, low-cost technology option for reducing reliance on petroleum transportation fuels. Produced commercially today in both the United States and Brazil, FFV passenger car and light-duty truck models can operate on ethanol or gasoline or on any mixture of these fuels. Several other countries, including Sweden, Canada, Germany and China, have also pursued FFV technology. FFV components and systems are designed for compatibility with both fuels and to maintain proper control of engine operating parameters over the range of ethanol/gasoline fuel ratios. When ethanol fueling facilities are in place, individual FFV operators or fleets can then elect to fuel with ethanol as well as with gasoline, encountering no significant differences in vehicle operation with either fuel or fuel mixture. Provided that progress with FFV introduction to date is continued and expanded, and provisions for adequate alcohol fueling infrastructure follow apace, alcohol fuel flexibility offers an achievable and inexpensive means of adding motor fuel supply diversity and substituting alcohol fuels for gasoline. Today in the U.S., however, nearly all of the expanding motor fuel market for ethanol fuel continues to be low-percentage (up to 10 percent) ethanol/gasoline blends used by the general gasoline vehicle population, with little ethanol being used in FFVs.

History of Flexible Fuel Vehicle Development

Efforts to develop practicable alcohol/gasoline multi-fuel or dual-fuel vehicle systems were pursued over many decades, including some reported on in the early International Symposia on Alcohol Fuels [1,2]. However, difficulties achieving variable engine calibration and seamless operation across a range of alcohol/gasoline blends constrained commercialization of such technology -- in favor of dedicated alcohol-fueled vehicles -- until the mid-1980s, when the introduction, by the Netherlands Research Institute for Road Vehicles, of an optical sensor capable of continuously and precisely measuring fuel alcohol content elicited auto industry interest[3]. The State of California, as part of its Methanol Fuel and Vehicle Program, successfully tested a single prototype methanol/gasoline FFV provided by Ford Motor Company in 1986 and subsequently demonstrated methanol/gasoline FFVs supplied by ten different auto companies between 1987 and 1993. The experience gained from these fleet demonstrations, involving about 900 vehicles of 16 different models operated by 90 participating fleets, led to commercial offerings of FFV models by the "Big Three" U.S. manufacturers beginning in 1992 [4]. Over 13,000 methanol/gasoline FFVs were sold in California by Ford, General Motors Corporation and Chrysler Corporation in the 1992 through 1998 model years, several thousand of which are still in use.

In the late 1990s, U.S. automakers underwent a transition from production of methanol/gasoline FFVs to production of ethanol/gasoline FFVs. This coincided with discontinuation of

California's Methanol Program and with increasing national emphasis on the domestic production and application of ethanol fuel. Since then, in the 1998 through 2004 model years, a reported 4.1 million ethanol/gasoline FFVs were sold in the U.S. market by Ford, General Motors and Daimler-Chrysler(5). A provision of the Alternative Motors Fuels Act (AMFA) of 1988 provides an incentive for the production of FFVs and other types of alternative fuel vehicles, in the form of a credit against an auto company's requirement for compliance with the federal Corporate Average Fuel Economy (CAFE) Standards. Most of the other manufacturers supplying the U.S. auto market have not yet elected to produce FFVs, although Nissan recently introduced that company's first FFV model.

Brazil, after decades of dedicated ethanol vehicle production, has more recently undertaken a move to ethanol/gasoline FFVs. Beginning with a Volkswagen FFV model introduced in 2003, the Brazilian auto industry has rapidly begun producing FFVs, encouraged by a government tax incentive. By the end of 2004, Brazilian automakers Volkswagen, Ford, General Motors, Fiat and Renault were producing a total of 23 FFV models for the Brazilian market, with approximately 380,000 FFVs sold (6).

Current Status of Flexible Fuel Vehicle Introduction and Ethanol Fuel Use

FFV technology has clearly gained a solid commercial footing in the U.S., achieving the largest inroad of any alternative fuel technology to date. As shown in Table 1, California's FFV population, currently at about 260,000, exceeds the next most numerous alternative fuel vehicle category, compressed natural gas vehicles, by nearly an order of magnitude. Still, these more than a quarter-million FFVs represent just one percent of California's on-road vehicles, (somewhat below the national percentage since some FFV models have not been sold in California). As indicated in Tables 2 and 3, the recent rate of new FFV sales in the state does not portend growth of this FFV market share, mainly due to changes in overall automaker FFV production and discontinuation of previous high-volume FFV models. And thus far, introduction of a fueling network for E85 -- 85 percent ethanol/15 percent gasoline, the maximum ethanol content fuel formulation approved for U.S. FFVs -- lags behind the vehicle population in most U.S. states, with FFVs continuing to operate mostly on gasoline. Exceptions include a number of government fleets and some commercial fleets electing to operate FFVs on E85, in some cases installing their own on-site fueling facilities. As shown in Table 4, about 27 percent of California's FFVs reside in fleets. Today in California, there are only three E85 fueling facilities in operation, one at a public retail station and two at federal government fleet sites. Twenty-two other U.S. states have yet to see their first E85 fueling station. California, meanwhile, has become the largest U.S. market for ethanol fuel, approaching one billion gallons per year of ethanol blended in gasoline as a substitute for the gasoline oxygenate additive MTBE, which the state banned at the end of 2003.

Table 1: Ethanol FFVs As Part Of California's Motor Vehicle Population

Vehicle Type	Gasoline	Diesel	**Ethanol FFV**	Hybrid gas/elec	CNG	Electric	LPG/ other	H2
Light-Duty	24,785,578	391,950	**257,698**	45,263	21,269	14,425	538	13
Heavy-Duty	372,849	471,340	**--**	--	5,401	806	1,172	--
source: California Energy Commission joint-agency data project with California Department of Motor Vehicles. Ethanol FFV data as of April 2005; all other data as of October 2004.								

Table 2: Growth of California's FFV Population

2002 to 2003	2003 to 2004	2004 to 2005	2002 to 2005 (cum.)
36%	26%	16%	98%
source: same as table 1; growth percentages are from April-to-April of each year			

Table 3: California's FFV Population Distribution by Model Year

1998	1999	2000	2001	2002	2003	2004	2005*
1%	9%	18%	14%	15%	26%	9.6%	6.6%
source: same as Table 1; data as of April 2005; *2005 model year sales through April 2005							

Table 4: California's FFV Population Distribution by Ownership Category

general public	car rental companies	businesses	federal govt	local govt	state govt
73%	11%	11%	2.7%	1.4%	0.7%
source: same as Table 1; data as of April 2005					

The State of Minnesota represents the notable example, thus far, as the U.S. state where E85 fuel availability is being most aggressively pursued. Minnesota has about 150 retail stations offering E85, with as many as 200 anticipated by the end of 2005. This represents E85 availability at about 5 to 7 percent of Minnesota's gasoline fueling stations, serving an ethanol FFV population currently estimated at 120,000 (roughly 2.5 percent of Minnesota's on-road vehicles). (7) Despite this example of progress with E85 availability, as shown in Table 5 most of the ethanol supply in Minnesota, as in other U.S. markets, flows to the gasoline blend market. Minnesota also has a state mandate for a 10 percent ethanol blend in virtually all gasoline, the maximum percentage currently accepted by U.S. automaker warranties for gasoline vehicles. And, as Minnesota's in-state ethanol production has outgrown the state's effectively saturated market for ethanol as a gasoline blend component, most of the added ethanol production is apparently finding its way into other states' ethanol/gasoline blend markets as opposed to the E85 FFV market. This is possible since, beyond Minnesota, the overall U.S. ethanol/gasoline blend market is using only about one-third of its potential (10 percent) ethanol volume. State legislation recently enacted in Minnesota increases the mandate for ethanol/gasoline blending to 20 percent ethanol by 2012, with an option for E85 market growth to substitute for this requirement.

Table 5: Minnesota Ethanol Production and Use (mill gals/yr)

year	1997	1998	1999	2000	2001	2002	2003	2004
Production	112	124	190	220	252	300	359	400
Total Use	177	200	240	248	254	258	261	260
E85 Use (# of stations)	0.006 (11)	0.04 (12)	0.08 (17)	0.3 (56)	0.7 (65)	1.3 (70)	2.2 (85)	2.6 (101)
sources: Groschen, R., presentation at Tenth National Ethanol Conference, Scottsdale, AZ, Feb. 2005; E85 data from Minnesota State Energy Office								

In Brazil, the picture with respect to the ethanol/gasoline blend market and the marketing of ethanol to the FFV market appears in sharp contrast to the above situation in the U.S. First of all, after many years of dedicated ethanol vehicle production and operation, ethanol availability is extensive, with E100 -- the nearly pure ethanol accepted for use in either dedicated ethanol vehicles or FFV s -- marketed at some 28,000 fueling stations. Secondly, Brazil has steadily increased its ethanol/gasoline blend percentage to 25 percent ethanol, a point at which the move to FFV production becomes the favored alternative to further increasing the standard ethanol percentage in gasoline and/or continuing production of dedicated ethanol vehicles. Finally, and perhaps most importantly, Brazil appears to be pursuing a definite transition to an all-FFV fleet as government policy, whereas U.S. FFV production continues to achieve only the modest inroad induced by the 1988 AMFA credits, amounting to perhaps 2 to 3 percent of new vehicle production at most.

Current retail pricing of E85 versus gasoline among existing E85 outlets in the U.S. reveals a further reason for the relatively low ethanol volumes being marketed as E85. An ongoing user-reported price survey of E85 stations in Minnesota and other Midwest U.S. states indicates that, while E85 is typically priced below gasoline on a per-gallon basis, the equivalent price (once the necessary adjustment for ethanol's lower energy content is applied) is still above that of regular unleaded gasoline. For the four-month period April-July 2005, the average E85 price at the surveyed stations was $1.69 per gallon, versus $2.09 per gallon for regular unleaded gasoline (8). Based on the relative E85-versus-gasoline fuel economies of 2005 ethanol FFV models reported by the U.S. Environmental Protection Agency, current FFVs use 1.34 gallons of E85, on average, to travel the same distance as on one gallon of gasoline (9). Applying this 1.34:1 adjustment factor to the above $1.69 per gallon average price of E85 yields a "gasoline equivalent" price of $2.26 per gallon, or $0.17 (8 percent) more than the average price of regular unleaded gasoline at the stations surveyed. Meanwhile, wholesale market prices reported for ethanol and gasoline at various U.S. terminal locations typically show more favorable comparative pricing for ethanol as a gasoline blending component (10). Furthermore, the above adjustment to achieve a gasoline-equivalent price is not normally applied when ethanol enters the gasoline blend market -- that is, a gallon of ethanol is effectively treated the same as a gallon of gasoline for purposes of blending as a low-percentage gasoline component.

Determining the Future of Alcohol Fuel Flexibility

Brazil appears to have embarked on a rather clear and straightforward course toward realizing the energy opportunity afforded by an ethanol FFV population, influenced and facilitated by that country's previous ethanol vehicle and fueling infrastructure progress. In contrast to Brazil, the course of alcohol fuel flexibility in the U.S. is at a juncture where the outcome is less certain. While selected FFV models have been in commercial production by the Big Three U.S. automakers for the past thirteen years, much remains to be settled before a role for this option in the nation's future motor fuel supply picture can be confidently defined. As exemplified by past alternative fuel vehicle commercialization initiatives that have not been sustained (for example, those involving methanol and electric vehicles), the current FFV market inroad does not guarantee the growth, or even the continuance of this option.

A key determinant is future U.S. government policy regarding inducements for expanded automaker production of FFVs. The Energy Policy Act of 2005 extends the AMFA CAFE credits through model year 2010, and gives the Secretary of Transportation authority to further extend the credits through 2014. This is despite continuing controversy surrounding this provision, which centers around the compromise these credits represent to automaker compliance with fuel economy standards, and the minimal alternative fuel availability and usage thus far.

This step, extending the life of the CAFE credits, is important for maintaining the current FFV market presence and keeping the technology viable, but does not assure expansion of the current FFV market share or in-use FFV population. Some further form of inducement will obviously be necessary before automakers can be expected to expand or introduce FFV model lines or move toward an all-FFV fleet, as is occurring in Brazil.

Meanwhile, the steps necessary to establish an adequate E85 fueling infrastructure and begin marketing significant volumes of ethanol to the widespread U.S. FFV market remain a daunting proposition. The perennial "chicken-and-egg" dilemma faced by all alternative fuel options with respect to the proper sequence and relative emphasis on vehicles versus fueling infrastructure is still in evidence. The sustained production of ethanol FFVs for 10 consecutive model years, and the market foothold resulting from this introductory level of production, are clearly a significant measure of progress. Two recent federal legislative provisions improve E85 fueling prospects: a 2004 change to the prevailing federal ethanol tax incentive that gives ethanol used as E85 the same tax benefit as ethanol used for gasoline blending; and a new income tax credit for alternative fueling (including E85) facilities included in the Energy Policy Act of 2005. However, unless substantial growth of the FFV population, up to a much larger share of on-road vehicles, can somehow be assured, widespread investment in E85 fueling infrastructure might still be difficult to justify. Without concerted initiatives on behalf of both expanded FFV production and E85 fueling stations, the ethanol/gasoline blend market could continue to be the most effective market for ethanol in the U.S.

Pursuing the opportunity for alcohol fuel flexibility and confronting the challenges to this opportunity in the U.S., at this point, requires redefining and restating the public policy case for this option. The evolution of FFV technology since its introduction nearly 20 years ago, along with coinciding changes in the overall motor vehicle and motor fuel picture during this time, certainly affect the case for the ethanol FFV option, with respect to both the costs and the benefits. Today's FFV models are produced as standard-production models, incorporating technology and components that continue to become both less costly and less different from gasoline-only models. A number of components and materials that were once unique to FFVs are now state-of-the-art for all gasoline vehicle production. Also, the auto industry is now finding it possible to eliminate the FFV alcohol fuel sensor and rely on exhaust gas sensing and other standard vehicle systems to control for varying fuel composition, another significant cost-reducing step. Thus, the incremental cost to the industry of producing full model lines of FFVs has been reduced to a very nominal amount, $100 per vehicle or less by some industry estimates.

At the same time, the reasons for pursuing alternative fuel vehicle technologies, including alcohol FFVs, have evolved considerably. Dramatic progress with motor vehicle emission control technology and cleaner gasoline formulations continues to diminish the emission differences that once favored alternative fuels with respect to regulated air pollutants. A review of the certified emission levels of 2005 FFV models sold in California reveals minor differences between the E85-versus-gasoline emissions of oxides of nitrogen (NOx), non-methane organic gases (NMOG) and carbon monoxide (CO), with very low emission levels of these pollutants on either fuel. As illustrated by the two FFV models summarized in Table 6, a current model FFV may emit somewhat more or somewhat less of a given pollutant on E85 versus gasoline, but emission levels for all FFV models and both fuels are well below California's stringent emission standards applicable to these vehicles. For perspective, the 2005 standards represent improvements of 75 percent for NOx, 86 percent for NMOG, and 66 percent for CO from mid-1980s standards, when FFV technology was first demonstrated. The emission differences between E85 and gasoline operation for the 2005 FFV models shown in Table 6 are within 5 percent or less of the emission-reduction improvement achieved over this twenty-year period. Thus, any arguments for an air quality benefit (or detriment) attributable to these vehicles have probably become trivial.

Table 6: Emission Levels of Two 2005 FFVs
(grams per mile @ 50,000 miles)

Vehicle Model	Fuel	NOx (CA std.=0.14)	NMOG (CA std.=0.10)	CO (CA std. =3.4)
2005 Ford Taurus	E85	0.03	0.047	0.6
	Gasoline	0.02	0.049	0.9
2005 Mercedes-Benz C 240	E85	0.01	0.043	0.2
	Gasoline	0.04	0.028	0.3
source: California Air Resources Board, On-Road New Vehicle and Engine Certification Program, Executive Orders; http://www.arb.ca.gov/msprog/onroad/cert/cert.php				

Emissions of greenhouse gases, on the other hand, more clearly favor FFVs when operating on ethanol fuel, according to studies by Argonne National Laboratory done on a full fuel cycle basis. One of Argonne's most recent studies found that an FFV operated on ethanol produced from corn results in 33 percent less carbon dioxide emissions than gasoline operation, and this CO2 reduction could be 70 percent or more for ethanol produced from cellulosic biomass [(11)]. However, it should be noted that the greenhouse gas reduction potential of ethanol is largely a function its fuel supply cycle, and is virtually the same for a gallon of ethanol that replaces gasoline in either the ethanol/gasoline blend market or the E85 FFV market.

The most compelling case for fully developing the ethanol FFV opportunity in the U.S. will most likely have to be made primarily from an energy standpoint -- based on the merits of ultimately achieving an on-road vehicle population capable of fueling at any time with two different fuels, one derived from petroleum, the other from various non-petroleum sources. And the benefits of capturing this opportunity may, in turn, rest to a large extent on the ultimate resource potential and supply availability foreseeable for ethanol as a source of the nation's motor fuel. The recently enacted goal of 7.5 billion gallons per year of renewable fuel use by 2012, contained in the Energy Policy Act of 2005, appears to be fully achievable via the ethanol/gasoline blend market, perhaps with a significant contribution of biodiesel as well. In fact, the U.S. ethanol/gasoline blend market could conceivably accept twice this volume of ethanol at today's 10 percent blend practice, and four times this volume if the 20 percent blend sought by Minnesota gains wide acceptance. Therefore, further steps toward an expanded ethanol FFV population and a national E85 fueling network should logically be matched with a national ethanol production and supply outlook.

Conclusions

The U.S., after two decades of FFV development, still faces major decisions regarding whether or not to seriously pursue the opportunity offered by alcohol fuel flexibility, and what steps constitute the best course with respect to this opportunity. Further national initiatives and investments aimed at expansion of FFV production and E85 fueling infrastructure need to be part of a clear overall national agenda for petroleum reduction and a specific strategy for the role of ethanol as a transportation fuel.

Brazil, within the last two years, has deployed FFVs for the first time and appears committed to a fully ethanol/gasoline flexible fuel vehicle fleet, with steps underway to bring this about. Alcohol fuel flexibility now emerges as the most effective course for Brazil after thirty years of ethanol fuel market development involving both ethanol/gasoline blending and dedicated ethanol vehicles.

Other countries evaluating the transportation energy opportunity offered by alcohol fuel flexibility stand to benefit from the U.S. and Brazilian experiences to date with FFV technology and alcohol fueling, and can choose well-designed strategic paths that best fit their own circumstances and objectives.

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