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Technical Report

Gasoline Equivalent Fuel Economy Determination for Alternate Automotive Fuels

by

Craig A. Harvey

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Control Technology Assessment and Characterization Branch
Emission Control Technology Division
Office of Mobile Source Air Pollution Control
Office of Air, Noise and Radiation
U.S. Environmental Protection Agency
2565 Plymouth Road
Ann Arbor, Michigan 48105

GASOLINE - EQUIVALENT FUEL ECONOMY DETERMINATION

Abstract

Due to the growing interest in and use of alternate automotive fuels, it is necessary that EPA provide a method of calculating fuel economy values for these vehicles than using fuels so that average fuel economies of manufacturers can be determined. The relevant legislation is reviewed, and various methodologies are discussed.

Possible fuel equivalency factors are presented for Diesel fuel, ethanol, methanol, gasohol, and natural gas. A methodology is recommended that takes into account the energy content of the fuel, the energy required to manufacture the fuel, and the value of the raw material used to make the fuel.

I. Introduction

A. Recommendation

In order to comply with the provisions of the Energy Policy and Conservation Act (EPCA, PL 94-163) (1)* and the Chrysler Corporation Loan Guarantee Act (PL 96-185) (2), which call for a determination of "... that quantity of any other fuel which is the equivalent of one gallon of gasoline," it is recommended that for the purpose of calculating the Fuel Economy Values for vehicles fueled with fuels which differ substantially from gasoline, a methodology similar to that used by Department of Energy (DOE) for electric vehicles (3) be applied. This methodology would account for fuel energy content and final processing energy requirement, and indirectly for energy input in the earlier processing steps.

In essence, this methodology would consist of taking the mile-per-gallon result from a vehicle test on an alternate (non-gasoline) liquid fuel and adjusting it by (1) the energy content ratio of gasoline to the alternate fuel (LHV, BTU/gal), (2) the ratio of processing energy efficiency of the alternate fuel to the efficiency of a petroleum refinery, and (3) the ratio of raw material costs of gasoline to those of the alternate fuel.

* Numbers in parentheses indicate references at the end of the report

The equation is:

$$FE = MPG_{alt.} \times \frac{LHV_{gas.}}{LHV_{alt.}} \times \frac{E_{alt.}}{E_{gas.}} \times \frac{V_{gas.}}{V_{alt.}}$$

where:

FE = gasoline equivalent Fuel Economy

MPGalt. = Mile per gallon test result for Alternate Fuel

LHVgas. = Lower heating value, standard test gasoline (BTU/gal)

LHValt. = Lower heating value, alternate fuel (BTU/gal)

Ealt. = Energy efficiency of processing plant, alternate fuel

Egas. = Energy efficiency of petroleum refinery (%)

Vgas. = Raw material value, gasoline ($/million BTU)

Valt. = Raw material value, alternate fuel ($/million BTU)

B. Purpose of Report

With the increasing national emphasis on energy conservation and energy independence, in conjunction with rapidly rising gasoline costs, the transportation industry, the energy industry, the U.S. Government, and other interested parties are putting more attention on development of vehicles/engines that either utilize petroleum fuels more efficiently or make more use of fuels derived from domestic energy resources. Some examples of this are the increased production of Diesel vehicles, the marketing of Gasohol, the development of alcohol-fueled vehicles, and the development of electric vehicles.

This report is intended to provide some of the basis for a decision on the most appropriate methodology for calculating the gasoline equivalent fuel economy of a vehicle that uses fuel other than gasoline. Once this methodology has been determined, it will provide vehicle manufacturers with a way to gauge the effects of alternative marketing options on their average fuel economy.

C. Background

C.1. Legislation

a) The Energy Policy and Conservation Act

The Energy Policy and Conservation Act (EPCA) mandates that the Secretary of Transportation establish average fuel economy standards for major automobile manufacturers and importers (production above 10,000 cars per year) beginning with the 1978 model year, as shown in Table 1. The 1980 standard was 20.0 mpg. The standard will increase progressively until the average fuel economy is 27.5 mpg, as required in 1985. The standard is to be met by each manufacturer and by each importer and applies to the total number of cars produced or imported.

Civil penalties are prescribed for a violator of the law: $5 for each tenth of a mile-per-gallon that their corporate average falls below the

Table 1.

<u>Automotive Average Fuel Economy Standards Under the Energy Policy and Conservation Act</u>

Model Year	Standard (mpg)
1978	18.0
1979	19.0
1980	20.0
1981	22.0
1982	24.0
1983	26.0
1984	27.0
1985 and thereafter	27.5*

*The Secretary of Transportation may alter this to the "maximum feasible average fuel economy", but such action may be disapproved by Congress for levels below 26.0 mpg or above 27.5 mpg.

year's standard, multiplied by the number of cars produced or imported that year. The National Energy Conservation Policy Act, P.L. 95-619, grants the Secretary of Transportation the authority to raise this penalty up to $10 for each tenth of a mile-per-gallon beginning in the 1981 model year. Credits for exceeding the standard are calculated in a similar manner.

For purposes of EPCA, "The term 'fuel economy' means the average number of miles traveled by an automobile per gallon of gasoline (or equivalent amount of other fuel) consumed, as determined by the EPA Administrator in accordance with procedures established under section 503 (d)."

Section 503 (d) contains the EPA mandate for activity on the fuel equivalency issue: " (1) Fuel economy for any model type shall be measured, and average fuel economy of a manufacturer shall be calculated, in accordance with testing and calculation procedures established by the EPA Administrator, by rule..." and " (2) The EPA Administrator shall, by rule, determine that quantity of any other fuel which is the equivalent of one gallon of gasoline."

Therefore, it is necessary to know what is meant by "equivalent" and what factors are included in it. Other references to equivalency in EPCA are as follows:

- Section 105 (b)(1) "... an average daily volume of 1,600,000 barrels of crude oil, natural gas liquids equivalents, and natural gas equivalents. (2) one barrel of natural gas equivalent equals 5,626 cubic feet of natural gas measured at 14.73 pounds per square inch (MSL) and 60 degrees Fahrenheit. (3) one barrel of natural gas liquids equivalent equals 1.454 barrels of natural gas liquids at 60 degrees Fahrenheit."

These values for quantities of natural gas and natural gas liquids that are equivalent to 1 barrel of crude oil are determined simply from the ratio of average energy content (heating value) of the fuels. There is no attempt to include any additional factors such as processing or transport energy requirements.

In Title III, Part B of EPCA, which deals with consumer products in general, these definitions are given:

> Section 321(a)(4) "The term 'energy use' means the quantity of energy directly consumed by a consumer product at point of use, determined in accordance with test procedures under section 323. (5) The term 'energy efficiency' means the ratio of the useful output of services from a consumer product to the energy use of such product, determined in accordance with test procedures under section 323."

> Section 322(6)(2)(B) "The Btu equivalent of one kilowatt-hour is 3,412 British thermal units."

From this it is apparent that the scope of consideration for these products includes only the energy consumed at the final point of use, and equivalency is determined by the direct conversion factor without including any additional energy input factors.

The objective of EPCA is to accomplish the purposes listed below:

> "SEC.2. The purposes of this act are-
>
> (1) To grant specific standby authority to the President, subject to Congressional review, to impose rationing, to reduce demand for energy through the implementation of energy conservation plans, and to fulfill obligations of the United States under the international energy program;
>
> (2) to provide for the creation of a Strategic Petroleum Reserve capable of reducing the impact of severe energy supply interruptions;
>
> (3) to increase the supply of fossil fuels in the United States, through price incentives and production requirements;

(4) to conserve energy supplies through energy conservation programs, and, where necessary, the regulation of certain energy uses;

(5) to provide for improved energy efficiency of motor vehicles, major appliances, and certain other consumer products;

(6) to reduce the demand for petroleum products and natural gas through programs designed to provide greater availability and use of this Nation's abundant coal resources; and

(7) to provide a means for verification of energy data to assure the reliability of energy data."

Examining EPCA, it is apparent that each of these points has been dealt with by specific sections of EPCA. For instance, points three and six, above are dealt with in Title I, "Matters Related to Domestic Supply Availability", Part A, "Domestic Supply" and in Title IV, "Petroleum Pricing Policy and Other Amendments to the Allocation Act"; point one is dealt with in Title II, "Standby Energy Authorities", and in Title V, part C, "Congressional Review". Point seven is dealt with in Title V, Part A, "Energy Data Base and Energy Information".

The above mentioned points do not deal with automotive fuel use at all, except in a very indirect way, which leaves points four and five. Point four is covered by Title III, Parts A - E of EPCA, which provide energy conservation programs for the automotive sector, other consumer products, state energy use, industrial energy use, and federal energy use. Point five is a narrower application of point four and is dealt with in the first two parts of Title III, which are (A) "Automotive Fuel Economy" and (B) "Energy Conservation Program for Consumer Products Other Than Automobiles".

The average fuel economy program is one of the programs called for in point four, and it is the only program from EPCA that addresses energy use by currently available automobiles. Average fuel economy as put forth in EPCA for gasoline-fueled vehicles, addresses only the energy efficiency of the vehicle itself in terms of miles per gallon. It does not include any provision for considering the energy efficiency of drilling, refining or fuel transport operations.

Therefore, there is nothing in EPCA itself which provides for the inclusion of factors other than vehicle energy efficiency in the calculation of fuel economy.

However, there is a House-Senate conference report (4) which accompanied the bill to make EPCA law. That report explained the differences between the House and Senate versions of the bill and explained what the compromise version ("conference substititue") was. Regarding fuel equivalency the conference report states, "It is anticipated that the EPA Administrator, in determining 'equivalent amount of other fuel' will make such determination on the basis of BTU equivalency of different quantitities of various fuels, taking into account energy required to process such fuels".

Since EPCA itself does not explicitly specify the inclusion of fuel processing energy in fuel equivalency calculations, but the conference report "anticipates" such inclusion, methods will be presented in Part II of this report to cover each of these possible approaches.

b.) The Energy Tax Act of 1978

The Energy Tax Act of 1978, P.L. 95-618 (5), imposes an excise tax on fuel-inefficient vehicles ("gas guzzlers") which may have an even more profound impact on the strategy employed by the automobile manufacturers to comply with the fuel economy standards than the $5 to $10 per tenth of a mile-per-gallon penalty contained in EPCA. Table 2 shows the severity of this tax. Imposition of the tax begins with vehicles whose fuel economy is approximately 5 mpg less than the current year's average fuel economy standard. The tax is steeply graduated, ranging in 1986, from $500 for each vehicle whose fuel economy is 5 to 6 mpg below the 1986 standard to $3850 for each vehicle whose fuel economy is over 15 mpg below the standard.

Table 2

The Gas Guzzler Tax (in dollars)

Vehicle Fuel Economy EPA Composite MPG		1980 (20.0)	1981 (22.0)	1982 (24.0)	1983 (26.0)	1984 (27.0)	1985 (27.5)	1986 (27.5)	
									Standard
Greater than	22.5			0		0		0	minus
	21.5-22.5			0		0		500	5 mpg
Greater than	21.0	0	0		0		0		
	20.5-21.5			0		0		650	
	20.0-21.0	0	0		0		500		
	19.5-20.5			0		0		850	
	19.0-20.0	0	0		0		600		
	18.5-19.5			0		450		1050	Standard
	18.0-19.0	0	0		350		800		minus
	17.5-18.5			200		600		1300	10 mpg
	17.0-18.0	0	0		500		1000		
	16.5-17.5			350		750		1500	
	16.0-17.0	0	200		650		1200		
	15.5-16.5			450		950		1850	
	15.0-16.0	0	350		800		1500		
	14.5-15.5			600		1150		2250	
	14.0-15.0	200	450		1000		1800		
	13.5-14.5			750		1450		2700	Standard
	13.0-14.0	300	550		1250		2200		minus
	12.5-13.5			950		1750		3200	15 mpg
Less than	13.0	550	650		1550		2650		
Less than	12.5			1200		2150		3850	

More interesting is the effect on a given model which is retained unchanged in a manufacturer's line. For example, if a vehicle's fuel economy is 15.1 mpg in 1980, it would not be subject to a gas guzzler tax. Beginning in 1981, it would have an ever-increasing tax levied--$350 in 1981, $600 in 1982, $800 in 1983, $1150 in 1984, $1500 in 1985, and $2250 in 1986. It is assumed that the effect of this tax will be to reduce the sale of gas guzzlers.

This progressive increase in penalty will probably result in earlier discontinuance of production of the less fuel-efficient vehicles in a manufacturer's line. Fewer very fuel-efficient vehicles will then be needed to achieve the average fuel economy standard. The result will be a tighter clustering of vehicles around the standard.

c) The Chrysler Corporation Loan Guarantee Act of 1979

The Chrysler Corporation Loan Guarantee Act of 1979 (P.L. 96-185) established:

> "a seven-year evaluation program of the inclusion of electric vehicles ... in the calculation of average fuel economy ... to determine the value and implications of such inclusion as an incentive for the early initiation of industrial engineering development and initial commercialization of electric vehicles in the United States."

The Administrator of EPA was, in consultation with the Secretaries of Energy and Transportation, to promulgate "regulations to include electric vehicles in average fuel economy calculations ..." by March 7, 1980. The Secretary of Energy has proposed "equivalent petroleum based fuel economy values" for various classes of electric vehicles, and final values have been promulgated (10 CFR Part 474). These equivalent values are to be reviewed annually and revised as necessary.

These "equivalent petroleum based fuel economy values" for electric vehicles were to be determined taking into account the following parameters:

"(i) The approximate electrical energy efficiency of the vehicles considering the vehicle type, mission, and weight;

(ii) The national average electricity generation and transmission efficiencies;

(iii) The need of the Nation to conserve all forms of energy, and the relative scarcity and value to the Nation of all fuel used to generate electricity;

(iv) The specific driving patterns of electric vehicles as compared with those of petroleum fueled vehicles."

According to the final rule issued by DOE, equivalent petroleum based fuel economy values for electric vehicles will be calculated in the following manner:

$$FE = FE_{ee} \times DPF \times e_t \times AF \times \frac{E_{total}}{\Sigma I_i V_i}$$

where:

FE = the equivalent petroleum-based fuel economy

FE_{ee} = the energy-equivalent fuel economy value (miles per gallon) (ref. 5)

conversion factor: $\frac{113{,}300 \text{ BTU}}{\text{gal}} \times \frac{1 \text{ KWH}}{3412 \text{ BTU}}$

DPF = driving pattern factor (1.00)

e_t = average national electricity transmission efficiency (= 0.91)

AF = Accessory Factor (= 1.00, no accessories; 0.90, heater; 0.81, heater plus air conditioning)

E_{total} = total amount of electricity generated from all fuel sources for the model year (quadrillion BTU, or quads)

I_i = input energy of fuel used to generate electricity from fuel source i (quads)

V_i = relative value factor of fuel source i

In section II. D of this paper the adaptation of the above procedure to alternative automotive fuels is discussed.

C. 2. Current Equivalency Methodologies

Up to now, tentative solutions to the equivalency issue have only been provided for two specific areas - Diesel fueled vehicles and electric vehicles. The documents that cover these provisions are:

1) Methodology for Calculation of Diesel Fuel to Gasoline Fuel Economy Equivalence Factors, Technical Support Report for Regulatory Action, January 1976 (Revised May 1976), EPA-ECTD report. (7)

2) Federal Register, Sept. 10, 1976, "Fuel Economy Testing; Calculation and Exhaust Emissions Test Procedures for 1977-1979 Model Year Automobiles."

3) Final Rule, 10 CFR Part 474, "Electric and Hybrid Vehicle Research, Development, and Demonstration Program; Equivalent Petroleum-Based Fuel Economy Calculation"; 1981. (3)

There has been much written on the subject of Diesel/gasoline fuel equivalency but, so far, the solution has been to weight them equally. In other words, the correction factor applied to Diesel fuel economy test results is effectively 1.0. This is because the higher energy content of Diesel fuel tends to be balanced by the decrease in refinery energy consumption with increasing Diesel fuel production.

In attempting to characterize the increase in energy availability (decrease in refinery energy consumption) with increasing Diesel fuel production percentage, many variables enter into the calculation. For instance, there are refinery-to-refinery differences, variations in refinery product mix with time, and variations in raw material (such as the sulfur content of the crude oil) with time and between refineries, all of which affect the process energy requirements at any given Diesel/gasoline production ratio. There are some specific problems with using the current Diesel/gasoline equivalency methodology as a basis for future equivalency determinations, and these issues are discussed in part II. B. of this report.

Regarding equivalent petroleum-based fuel economy calculations for electric vehicles, the methodology in use was discussed previously in Section C.1.c) of this report.

II. Possible Methodologies for Determining Equivalent Fuel Economies for all Fuels

Following are three methodologies for calculating equivalent petroleum-based fuel economies for a wide variety of potential automotive fuels. One objective of this investigation is to determine a methodology that is consistent for all automotive fuels, so a range of possible solutions is presented including one solution (C) that is recommended due to its consistency with the various legislative provisions outlined above.

Method A. Fuel Energy Content Considered

The simplest solution that would be in line with EPCA, but not necessarily with the conference report as discussed in Part I, would be to use the ratio of the heat content of a fuel to that of gasoline as a correction factor to the actual mile per gallon test result. This would effectively rank vehicles on the basis of miles per BTU of fuel used by the vehicle itself.

Here is an example of this methodology as applied to a methanol-fueled vehicle: In the fuel economy test assume a vehicle gets 20 miles per gallon of methanol, as compared to a similar, but gasoline-fueled, car getting 30 miles per gallon. Since the heat content of methanol is 56,123 BTU/gal, the methanol-fueled vehicle is getting 35.6 miles per 100,000 BTU. Typical gasoline has a heat content of 113,300 BTU/gal, so 30 mpg gasoline equals 26.5 miles per 100,000 BTU.

In order to adjust the mile per gallon value for methanol (20 mpg) to correct for the difference in heat content between methanol and gasoline, it would be multiplied by the ratio of the heat content of gasoline to that of methanol.

$$FE = MPGalt. \times \frac{LHVgas.}{LHValt.}$$

$$FE = 20 \text{ mpg} \times \frac{113{,}300 \text{ BTU/gal gasoline*}}{56{,}123 \text{ BTU/gal methanol(8)}}$$

$$FE = 20 \text{ mpg} \times 2.02$$

$$FE = 40.4 \text{ mpg}$$

In this case, for purposes of fuel economy calculations, the 20 mpg methanol car could be rated at 40.4 mpg when converted to a gasoline-equivalent basis.

Another fuel that should be mentioned with respect to Method A is Diesel fuel. Since Diesel fuel #2 has a 15% higher heat content than gasoline (130,650 (7) vs. 113,300 BTU/gal), the equivalent gasoline-based fuel economy of a 35 mpg Diesel vehicle, for instance, would be;

$$FE = 35 \text{ mpg} \times \frac{113{,}300 \text{ BTU/gal gasoline}}{130{,}650 \text{ BTU/gal Diesel}}$$

$$FE = 30.4 \text{ mpg}$$

Table 3 lists the fuel equivalency factors for various fuels calculated with this methodology. FEF is the resultant adjustment factor, for methanol for example, the value for FEF is 2.02.

* Today's motor gasolines range in BTU/gallon from about 112,000 BTU/gallon to 115,000 BTU/gallon.

Table 3

Fuel Equivalency Factors
Based on Energy Content alone

Fuel		Energy Content* (BTU/gal)	FEF
Gasoline	leaded regular	113,300	1.0
	unleaded regular	113,300	1.0
	unleaded premium	113,300	1.0
Diesel Fuel	#2	130,650	0.87
	#1	126,100	0.9
Methanol		56,123	2.02
Ethanol		78,987	1.43
Gasohol		109,869	1.03
Natural Gas		(1080 BTU/ft^3)	**

*Lower Heating Value
** FE = Miles/BTU nat. gas x 113,300 BTU/gal. gasoline

The use of this methodology for Diesels could be taken to represent a 13% penalty that could discourage use of Diesel vehicles (9). However, when combined with the 30% average fuel economy benefit for Diesels over comparable gasoline vehicles (10), there is still a 17% benefit for Diesels.

The only possible liability of this methodology is that, by itself, it does not address the issue of energy used in processing fuels. This area of concern is addressed in the next two methodologies.

Method B. Energy Content Plus Refining Energy Considered

A second possible approach to determining gasoline equivalent fuel economies would be one that includes the efficiency of the final fuel processing steps, (eg. refinery efficiency for petroleum fuels).

In this methodology an additional factor is included in the fuel equivalency calculation. In the case of Diesel vehicles this additional factor adjusts the fuel economy value to reflect the refinery energy savings that occur when the Diesel fuel output of a refinery is increased relative to the gasoline output. The most recent investigation of this phenomenon is described by Amoco in reference (11).

In the Amoco study it is concluded that decreasing the Gasoline/Distillate (G/D)* production ratio from 1.6 to 0.7 would decrease the energy consumption of the refinery by 13.7% - 16.8%, depending on the octane of the gasoline produced.

The equation which characterizes this methodology for finding the gasoline-equivalent fuel economy of a Diesel vehicle is:

$$FE = MPG_D \times \frac{LHVgas}{LHV_D} \times \frac{DEO}{DEO - RES},$$

where: The subscript D indicates Diesel fuel
DEO is the Diesel fuel energy output
RES is the Refinery Energy Savings when producing additional Diesel fuel

* G/D ratio is the volume of motor gasoline divided by the volume of total distillates - Diesel fuel, fuel oils, kerosene and jet fuels. It is commonly used to describe refining operations. U.S. refineries currently average about 1.6 G/D ratio, but the ratio may vary among refineries and with season from about 1.0 to 2.0

The combination of LHV gas x Diesel Energy Output adjusts the Diesel fuel energy output at any G/D ratio to the equivalent gasoline energy output. The term in the denominator reflects the refinery energy savings that occur when producing additional Diesel fuel. This increases the Diesel equivalency factor because it gives the Diesel fuel energy output credit for the refinery energy saved.

Using this methodology Amoco then developed the following table of Diesel Equivalency Factors (DEF), which would be used in this formula:

$$FE = MPG_D \times DEF$$

DIESEL EQUIVALENCY FACTORS
BASED ON ALL DIESEL Fuel PRODUCED

Pool RM/2 Octane*	Gasoline/Distillate Ratio 1.6	1.3	1.0	0.7
80	0.88	0.91	0.92	0.92
82	0.88	0.91	0.92	0.92
84	0.88	0.91	0.92	0.93
86 (Base)	0.88	0.92	0.93	0.92
88	0.89	0.94	0.94	0.94
90	0.89	0.96	0.97	0.96
92	0.90	0.98	0.97	0.98

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* $RM/2 = \text{Anti-knock Index (AKI)} = \frac{\text{Research Octane + Motor Octane}}{2}$

From the MVMA national gasoline survey, the difference between Research and Motor octane (sensitivity) of unleaded gasoline typically ranges from 9.0 for regular to 9.6 for premium. So 91 Research Octane unleaded would have an AKI of about 86.5.

For any fuel equivalency methodology, a specific base fuel needs to be used as a reference point. Unleaded 91 Research Octane gasoline is the most suitable choice for such a reference fuel.

DIESEL EQUIVALENCY FACTORS
BASED ON ADDITIONAL DIESEL FUEL ONLY

Pool RM/2 Octane	Gasoline/Distillate Ratio 1.6	1.3	1.0	0.7
80	0.88	0.93	0.93	0.93
82	0.88	0.94	0.93	0.93
84	0.88	0.94	0.94	0.93
86 (Base)	0.88	0.95	0.94	0.93
88	0.89	0.99	0.96	0.95
90	0.89	1.02	0.99	0.98
92	0.90	1.04	1.00	1.00

It should be mentioned that Amoco also calculated a set of DEF's that included the expected fuel economy advantage for gasoline-fueled vehicles attributable to increasing gasoline octane number (1.5 mpg per RM/2). However, it would be incorrect to include this effect in the Diesel Equivalency Factor, since any expected fuel economy change, if valid, would show up in the actual mpg test results.

The above factors are based on the change that would occur from what is considered the base case (86 RM/2; 1.6 G/D). Therefore, the DEF for the base case consists only of the energy content (lower heating value) of gasoline divided by the energy content of Diesel fuel. In theory it would be possible to avoid this somewhat arbitrary base case, but it would require many assumptions on allocation of the energy used in each processing unit to each product. This is due to the many interdependencies of gasoline and Diesel fuel production which make it impossible to simply separate and measure the energy consumption attributable to each of the two fuels.

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In order to choose the most appropriate factor(s) from these tables, it is necessary to look a little more closely at things that affect the gasoline/distillate ratio. Distillate fuels include automotive (passenger car and truck) Diesel fuels, jet aircraft fuel, residential and commercial heating oil, and industrial Diesel fuels.

According to the DOE predictions in reference (12), increases that will occur in the use of distillate fuels for transportation in the next decade will be offset somewhat by decreases in the other distillate fuel uses. Due to these decreases in non-transportation distillate fuels, the net change in gasoline/distillate ratio is not as great as might be expected.

Even if we assume all jet fuel is distillate, the GDR in 1985 only comes down to about 1.45, and in 1990 it would range from 1.28 - 1.34 depending on crude oil prices. Therefore, the 1.3 GDR column would be the most appropriate one to consider through at least 1990, assuming the changes that actually occur fall within the range of the DOE predictions.

The question of whether to base the DEF on all Diesel fuel produced or just on the additional Diesel fuel produced is handled in the Sobotka report (13) by simply neglecting the existence of the all-Diesel-fuel factors. However, a valid rationale does exist for using the additional-Diesel-fuel factors, as Sobotka did.

The refinery efficiency credit from decreasing GDR should be credited to that portion of the distillate production which is most responsible for the change. According the DOE projections, most of the distillate increase can be attributed to the automotive sector (80% vs. 20% jet fuel) and furthermore, all of that increase can be attributed to Diesel passenger cars, since truck vehicle-miles are expected to be less in 1990 than in 1978 (12).

Therefore, the Sobotka analysis was correct in using the equivalency factors based on additional Diesel fuel production only. Also, as described in the Sobotka analysis, the unleaded gasoline pool AKI is expected to increase from the base case of 86 to 88 in the 1980's and possibly 90 in the 1990's. So the range of DEF's would be 0.95 - 1.02.

For this methodology it is recommended that, due to the uncertainties in these calculations, the fuel equivalency factor for Diesels be rounded to 1.0, thus in effect, keeping it as it has been up to this point.

Another question with this type of methodology is how to apply it to other fuels, such as alcohols. It is possible to define reasonably accurate production efficiencies, and therefore energy consumptions, for the common ethanol and methanol production processes within this methodology. But it would not be possible to define a valid fuel equivalency factor directly relating alcohol to gasoline, since there is no direct relationship between alcohol and gasoline production like there is between Diesel and gasoline. Futhermore, a corresponding efficiency for gasoline by itself would not be calculable due to the refinery interdependencies mentioned above.

Despite these considerations, a possible approximation of an alcohol/gasoline equivalency factor within this basic methodology could be calculated as follows: 1) let the gasoline production efficiency be approximated as simply the overall refinery efficiency.

$$E_{gas.} = \frac{REO}{REI} = \frac{REI - REC}{REI}$$

where:

Egas. = Energy efficiency of petroleum refinery

REO = Total refinery energy output

REI = Total refinery energy input

REC = Refinery energy consumption

2) then let the alcohol production efficiency be calculated with this same equation as applied to alcohol fuel plants. The following is how this would look for ethanol.

$$Eeth. = \frac{PEI - PEC}{PEI}$$

where:

Eeth. = Energy efficiency of alternate fuel plant (ethanol)
PEI = Total plant energy input
PEC = Plant energy consumption

and 3) The equivalency factor would then be the fuel energy content ratio multiplied by the ratio of the two fuel processing efficiencies.

$$FE = MPGeth. \times \frac{LHVgas.}{LHVeth.} \times \frac{Eeth.}{Egas.}$$

Due to the likelihood of change in average production efficiency with technological improvements and new plant construction, it probably would be necessary to review and update these factors periodically.

<u>Example (methanol) #1</u>

$$Egas. = \frac{REO}{REI} = 0.92 \quad \text{(ref. 11)}$$

$$Emeth. = \frac{PEO}{PEI} = 0.56 \quad \text{(ref. 14, methanol from natural gas)}$$

$$FE = MPGmeth. \times \frac{113{,}300 \text{ BTU/gal}}{56{,}123 \text{ BTU/gal}} \times \frac{0.56}{0.92}$$

$$= MPGmeth. \times \underline{\underline{1.23}}$$

<u>Example (methanol)</u> #2

Emeth. = 0.60 (ref. 15, methanol and synthetic natural gas from coal)

$$FE = MPGmeth. \times \frac{113{,}300}{56{,}123} \times \frac{0.60}{0.92}$$

$$= MPGmeth. \times \underline{\underline{1.32}}$$

Table 4 lists fuel equivalency factors determined with Method B.

Table 4

Fuel Equivalency Factors
Based on Fuel Energy Content & Plant Process Energy

Fuel		Plant Efficiency	FEF*
Gasoline		92%	1.00
Diesel Fuel		92%	.95 - 1.02
Methanol	from natural gas	56% - 70%	1.23 - 1.54
	from coal	50% - 60%	1.10 - 1.32
Ethanol	from corn	45% - 60%	0.70 - 0.93
Gasohol	(10% of Ethanol effect)		.97 - .98
Compressed Natural Gas		96%	**
Liquified Natural Gas		86%	**

* FEF = FEF from Table 3 x $\frac{E\ alt.}{Egas.}$

** FE = (Miles/BTU nat. gas) x 113,300 x Plant Efficiency/92%

Method C. Energy Content, Process Efficiency Plus Fuel Value Considered

This fuel equivalency alternative is based on the Department of Energy (DOE) proposed methodology for calculation of equivalent petroleum-based fuel economies for electric vehicles which was described earlier in Section I. This methodology accounts not only for the different energy contents of the fuels themselves and the different energy efficiencies of the various fuel processing routes, but also includes a raw material cost factor to account for the energy needed to get a fuel as far as the processing step.

The raw material assumed for gasoline production is crude oil, so gasoline produced by any other means than refining of crude oil would need to have a fuel equivalency factor calculated to account for any significant differences in processing efficiencies and raw materials.

The raw material cost factor would be simply a ratio of the cost of crude oil to the cost of any alternate raw material, on a dollar per BTU basis.

When this factor is included in the formula for calculating FEF's, the equation looks like this:

$$FEF = \frac{LHVgas.}{LHValt.} \times \frac{Ealt.}{Egas.} \times \frac{Vgas.}{Valt.}$$

where:

Vgas. = Raw Material Value for gasoline ($/million BTU of crude oil)

Valt. = Raw Material Value for alternate fuel ($/million BTU)

Using some projected figures for 1982 (12), Table 5 indicates the effect of including this additional factor. For methanol, the inclusion of this raw material cost factor more than compensates for the lower processing efficiency of methanol compared to petroleum products. The resulting fuel equivalency factor, 3.76 - 5.42 depending on raw material, would seem to provide a significant impetus toward development and use of methanol fueled vehicles.

Even if a methanol fueled vehicle only achieved half the mpg of a corresponding gasoline vehicle, the FEF would result in a gasoline-equivalent fuel economy 1.88 - 2.71 times as much as the gasoline fueled vehicle.

The figures for ethanol are a little surprising due to the effect of the corn cost on the FEF. The cost of the corn needed to produce one million BTU of ethanol is about 5 1/2 times the cost of the heat source, assuming coal is used. Even when credit is given for the plant output of Distillers Dried Grain (DDG) the raw material cost per million BTU output of an ethanol plant is 1.9 times as high as a petroleum refinery operating with a current product mix.

So even if a pure ethanol-fueled vehicle achieved the same mpg test result as a gasoline-fueled vehicle (e.g. 25 mpg) the resulting gasoline-equivalent fuel economy would only be 1/1.9 (=0.53) times the ethanol test result (0.53 x 25 = 13.3 mpg).

Table 5

Fuel Equivalency Factors

Based on Energy Content, Plant Efficiency and Raw Material Cost

Fuel		Raw Material Cost	FEF*
Gasoline (from petroleum)**		$6.89/MMBTU	1.0
Diesel Fuel (from petroleum)**		$6.89/MMBTU	0.95 - 1.02
Methanol	(from natural gas)	$2.25/MMBTU	3.76 - 4.71
	(from coal)	$1.45/MMBTU	5.23 - 6.27
Ethanol*** (from corn) and all process energy from coal @$1.45/MMBTU for the coal		$3.50/bu	0.60 - 0.73
Gasohol			0.96 - 0.97
Natural Gas		$2.25/MMBTU	****

* FEF = FEF from Table 4 x $\frac{\text{Petroleum Cost}}{\text{Raw Material Cost}}$

** from petroleum at $37.88/barrel.

*** The higher FEF assumes all process energy comes from the input corn without any additional process energy source.

**** Gasoline - Equivalent Fuel Economy $= \frac{\text{Miles}}{\text{Btu}_{\text{nat. gas.}}} \times \frac{113{,}300\ \text{BTU}}{\text{gal. gasoline}} \times \frac{\text{plant eff.}}{92\%} \times \frac{\$6.89}{\$2.25}$

Gaseous and Other Fuels

The methodology discussed here could also be applied to other fuels besides those listed in the tables. For instance, it is possible to produce gasoline from coal rather than from crude oil. This would result in different raw material costs as well as different processing efficiencies for the synthetic gasoline in comparison to usual oil-derived gasoline.

To get a rough idea of how a synthetic gasoline such as this would compare to the fuels considered in the tables, it could be directly compared to methanol from coal. For the purpose of this comparison, we can assume that the raw material (coal) is the same in both cases, and that the processing efficiencies are approximately the same for converting coal to either gasoline or methanol. Then the only part of the Fuel Equivalency Factor that would be different for the two fuels would be the energy content (LHV) which, for the gasoline, would be double that of the methanol. The FEF computation would look like this:

Ealt. = 0.60 (using example #2, page 23)

Valt. = $1.45/MMBTU (from table 5)

FEF (methanol from coal) = 6.27 (table 5)

FEF (gasoline from coal) = 3.14

Since synthetic gasoline could be expected to yield approximately the same measured fuel economy as conventional gasoline, the final gasoline-equivalent fuel economy of the synthetic gasoline, according to these calculations, would be approximately triple that of conventional gasoline.

For liquid alternate fuels, as discussed above, the basic approach starts with measuring the fuel consumption (mile/gallon) and then multiplying it by the energy content ratio of gasoline to alternate fuel to obtain a gasoline-equivalent fuel economy. For gaseous fuels, the more likely starting point would be a mile per BTU measurement. This would then simply be multiplied by the energy content of gasoline (BTU/gal) to get the basic gasoline-equivalent fuel economy corresponding to Method A. The other adjustment factors for Methods B and C could then be applied as described above.

III. DISCUSSION

Three different methodologies have been presented here which cover a range of approaches for dealing with the fuel equivalency issue. Other methodologies were considered, such as basing equivalency solely on retail price per BTU, but it is felt that the methodologies presented here sufficiently encompass all the possibilities.

Looking first at Method A presented above (fuel energy content only), it is apparent that the factors not accounted for would include (a) plant/refinery energy consumption, (b) fuel transport energy consumption, and (c) differences in origin of fuel (imported crude, domestic coal, corn, etc.). It should be kept in mind that the Energy Policy and Conservation Act (EPCA) itself does not specifically call for any of these factors to be taken into account for non-electric vehicles.

In Method B (fuel energy content/process efficiency) the differences in fuel origin and energy consumption prior to reaching the plant/refinery are still not taken into account. (Again, these are not specifically required by EPCA.)

The major inconsistency introduced by this methodology is the way Diesel fuel equivalency would be handled compared with other fuels. For the process energy of Diesel fuel relative to that of gasoline it was necessary to consider the change in overall plant efficiency when the gasoline/distillate ratio was changed from an arbitrary baseline. This approach was due to the virtual impossibility of separating the efficiencies for Diesel and gasoline production since they are produced in the same plant from the same raw material and have many interdependencies in the production process.

This is in contrast to the handling of non-petroleum fuels within this methodology. For these other fuels, such as methanol, the production efficiency would be an actual, current efficiency to be compared directly with the current gasoline production efficiency. Not only would this be inconsistent with the handling of Diesel fuel equivalency, but it is also a very imprecise comparison due to the inability to determine an efficiency for gasoline by itself. (The overall refinery efficiency would be a composite of all the refinery products).

In Method C (energy content/efficiency/raw material value), the plant energy consumption is accounted for directly, while the fuel transport energy consumption, and the differences in origin of fuel are all taken into account indirectly via the raw material cost factor (price per BTU). The more energy that is consumed in getting raw material to the plant whether crude oil, coal, or corn, the higher the cost will be. Some of the factors that could influence the cost of the raw material to the plant are a) the cost of drilling, mining or growing it in the first place: b) the cost of transporting it to the plant, whether by pipeline, ship, rail or truck; and c) any taxes such as import duties; d) any subsidies granted to domestic drilling, mining or farming activities, or direct government price controls on raw materials such as oil, coal, and corn.

Since these cost factors include more than just direct energy dependent costs, the use of this factor actually goes a little beyond the legislated requirement for liquid fuels equivalency factors. Using a factor such as this would, however, be consistent with one of the parameters given for fuel equivalency calculation of electric vehicles in the Chrysler Corporation Loan Guarantee Act (PL 96-185), which takes into account the need of the nation to conserve all forms of energy, and the relative scarcity and value to the nation of various fuels.

Therefore, taking into account the various fuel equivalency methodologies and the legislative requirements, Method C seems to best serve the purposes set up for fuel equivalency determination provided all the needed input data can be accurately determined and updated when and if necessary.

APPENDIX

This Appendix gives some more calculations of Fuel Equivalency Factors (FEFs) for various parameters such as the efficiency of various production processes and costs of various raw materials.

Table A-1

Fuel Equivalency Factors

Considering fuel energy content and process energy

Methanol Plant Efficiency	Petroleum Refinery Efficiency 88%	90%	92%
50%	1.14	1.11	1.09
60%	1.36	1.33	1.30
70%	1.59	1.56	1.52
Ethanol Plant Efficiency			
30%	0.49	0.48	0.47
45%	0.73	0.72	0.70
60%	0.98	0.95	0.93
Natural Gas* Efficiency			
96% (compressed)	1.09	1.07	1.05
86% (liquified)	0.98	0.95	0.94

* Since it is not expected that mile/gallon figures will be found for natural gas fueled vehicles, the gasoline-equivalent fuel economy would be calculated as follows:

$$\text{Gasoline-Equivalent Fuel Economy} = \frac{\text{miles}}{\text{BTU natural gas}} \times \frac{113{,}300 \text{ BTU}}{\text{gal. gasoline}} \times \text{FEF}$$

Table A-2

Fuel Equivalency Factors
Methanol

Petroleum Refinery Efficiency and Cost

Raw Material/Plant Efficiency/Cost	88% L*	88% M*	88% H*	90% L	90% M	90% H	92% L	92% M	92% H
coal/50%/L**	4.77	6.36	7.95	4.66	6.22	7.77	4.56	6.08	7.60
coal/50%/M**	3.65	4.87	6.08	3.57	4.76	5.94	3.49	4.66	5.82
coal/50%/H**	2.95	3.94	4.92	2.88	3.85	4.81	2.82	3.77	4.71
coal/60%/L	5.73	7.64	9.55	5.60	7.47	9.33	5.48	7.30	9.13
coal/60%/M	4.38	5.84	7.30	4.28	5.71	7.14	4.19	5.59	6.98
coal/60%/H	3.55	4.73	5.91	3.47	4.62	5.78	3.39	4.52	5.65
coal/70%/L	6.68	8.91	11.14	6.53	8.71	10.89	6.39	8.52	10.65
coal/70%/M	5.11	6.81	8.52	5.00	6.66	8.33	4.89	6.52	8.15
coal/70%/H	4.14	5.52	6.89	4.04	5.39	6.74	3.96	5.28	6.59
nat.gas/50%/L***	3.10	4.14	5.17	3.03	4.04	5.06	2.97	3.96	4.95
nat.gas/50%/M***	2.07	2.78	3.45	2.02	2.70	3.37	1.98	2.64	3.30
nat.gas/50%/H***	1.55	2.07	2.59	1.52	2.02	2.53	1.48	1.98	2.47
nat.gas/60%/L	3.72	4.96	6.20	3.64	4.85	6.07	3.56	4.75	5.93
nat.gas/60%/M	2.48	3.31	4.14	2.43	3.24	4.04	2.37	3.17	3.96
nat.gas/60%/H	1.86	2.48	3.10	1.82	2.43	3.03	1.78	2.37	2.97
nat.gas/70%/L	4.34	5.79	7.24	4.25	5.66	7.08	4.15	5.54	6.92
nat.gas/70%/M	2.89	3.86	4.83	2.83	3.77	4.72	2.77	3.69	4.62
nat.gas/70%/H	2.17	2.90	3.62	2.12	2.83	3.54	2.08	2.77	3.46

		Raw Material Costs L	M	H
*	crude oil, $/bbl	30.00	40.00	50.00
**	coal, $/ton	31.20	40.80	50.40
***	natural gas, $/million BTU	2.00	3.00	4.00

Table A-3

Fuel Equivalency Factors

Method C for Ethanol

Petroleum Refinery Efficiency and Cost

Raw Material/Plant Efficiency/Cost	88%			90%			92%		
	L*	M*	H*	L	M	H	L	M	H
corn/30%/L	.44	.58	.73	.43	.57	.71	.42	.56	.70
corn/30%/M	.40	.53	.67	.39	.52	.65	.38	.51	.64
corn/30%/H	.37	.49	.62	.36	.48	.60	.35	.47	.59
corn/45%/L	.71	.95	1.19	.70	.93	1.16	.68	.91	1.14
corn/45%/M	.65	.87	1.09	.64	.85	1.07	.63	.83	1.04
corn/45%/H	.60	.81	1.01	.59	.79	.99	.58	.77	.96
corn/60%/L	.76	1.01	1.26	.74	.99	1.23	.72	.96	1.21
corn/60%/M	.70	.94	1.17	.69	.92	1.15	.67	.90	1.12
corn/60%/H	.66	.88	1.09	.64	.86	1.07	.63	.84	1.05

Raw Material Costs

		L	M	H
*	crude oil, $/bbl	30.00	40.00	50.00
**	coal, $/ton	31.20	40.80	50.40
***	corn, $/bushel	3.30	3.50	3.70

assuming coal is used for all the process energy

Table A-4

FUEL EQUIVALENCY FACTORS

FOR NATURAL GAS

(A) Compressed, (B) Liquified

Petroleum Refinery Efficiency and Cost

Raw Plant Material/Efficiency/Cost*	88%			90%			92%		
	L	M	H	L	M	H	L	M	H
(A)									
Natural gas/96%/L	2.98	3.97	4.96	2.91	3.88	4.86	2.85	3.80	4.75
Natural gas/96%/M	1.99	2.65	3.31	1.94	2.59	3.24	1.90	2.53	3.17
Natural gas/96%/H	1.49	1.99	2.49	1.46	1.94	2.43	1.42	1.90	2.37
(B)									
Natural gas/86%/L	2.67	3.56	4.45	2.61	3.47	4.35	2.55	3.41	4.26
Natural gas/86%/M	1.78	2.37	2.97	1.74	2.32	2.90	1.70	2.27	2.84
Natural gas/86%/H	1.33	1.78	2.23	1.31	1.74	2.18	1.27	1.70	2.12

$$\text{Gasoline - Equivalent Fuel Economy} = \frac{\text{miles}}{BTU_{ng}} \times \frac{113{,}300\ \text{BTU}}{\text{gal gasoline}} \times \text{FEF}$$

*Raw Material Costs

	L	M	H
natural gas, $/MMBTU	2.00	3.00	4.00
crude oil, $/bbl	30.00	40.00	50.00

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