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MASTER

HYBRID VEHICLE POTENTIAL ASSESSMENT

Volume 8: Scenario Generation

By
K. O. Leschly

September 30, 1979

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Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

U. S. DEPARTMENT OF ENERGY

Division of Transportation Energy Conservation

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ELECTRIC AND HYBRID VEHICLE SYSTEM
RESEARCH AND DEVELOPMENT PROJECT
HYBRID VEHICLE POTENTIAL ASSESSMENT
VOLUME VIII. SCENARIO GENERATION

September 30, 1979

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PREFACE

In 1976, Congress passed the Electric and Hybrid Vehicle (EHV) Research, Development, and Demonstration Act of 1976, Public Law 94-413, later amended by Public Law 95-238. The Department of Energy is conducting an EHV development program in compliance with that Law. The EHV System Research and Development Project, one element of this Program, is being conducted by the Jet Propulsion Laboratory (JPL) of the California Institute of Technology through an agreement with the National Aeronautics and Space Administration. This report presents the results of the investigations conducted under the Hybrid Vehicle Potential Assessment Task which is a part of the EHV Systems R&D Project.

Early results of this study were used as the technical basis for the Near Term Hybrid Vehicle Development Program now being carried out by the JPL Electric and Hybrid Vehicle System Research and Development Project.

This report is in ten volumes. Volume I contains an overview of the study and the major findings. Volumes II through X are of technical supplementary reports that describe the details of the study and present the most important data generated by the study elements.

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Volumes Comprising the Hybrid Vehicle Potential Assessment

Report No.	Subject	Author(s)
5030-345, Vol. I	Summary	F. T. Surber et al.
5030-345, Vol. II	Mission Analysis	F. T. Surber G. K. Deshpande
5030-345, Vol. III	Parallel Systems	S. P. DeGrey
5030-345, Vol. IV	Series Systems	Z. Popinski
5030-345, Vol. V	Flywheel Systems	S. G. Liddle
5030-345, Vol. VI	Cost Analysis	K. S. Hardy
5030-345, Vol. VII	Hybrid Vehicle Review	K. O. Leschly
5030-345, Vol. VIII	Scenario Generation	K. O. Leschly
5030-345, Vol. IX	Power Train Summary, Component Descriptions, HYVEC Vehicle Simulator	S. G. Liddle S. P. DeGrey
5030-345, Vol. X	Electric and Hybrid Vehicle Cost Handbook	R. C. Heft S. C. Heller

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1. INTRODUCTION

The scenarios described in this report have been generated in support of the Hybrid Vehicle Potential Assessment Task under the JPL Electric and Hybrid Vehicle Systems Research and Development Project.

The primary function of the scenario generation is to develop a set of consistent and credible forecasts required to estimate the potential impact of hybrid vehicles on future petroleum consumption in the USA, given a set of specific electric, hybrid and conventional vehicle designs. The forecasts are limited to the next 32 years (1978-2010), and the four major areas of concern are:

- Population and vehicle fleet size
- Travel patterns and vehicle fleet mix
- Conventional vehicle technology (Otto baseline)
- Battery technology
- Prices

The forecasts have been generated to reflect two baseline scenarios, a Petroleum Conservation Scenario (Scenario A) and an Energy Conservation Scenario (Scenario B). The key distinctions between these two baseline scenarios are listed in Table 1.

The primary assumption in Scenario A is higher gasoline prices than in Scenario B. This should result in less travel per car and an increased demand for smaller and more fuel efficient cars (compared to Scenario B).

In Scenario B the primary assumption is higher prices on cars (new as well as used) than in Scenario A. This should lead to less cars (compared to Scenario A) and a shift to other modes of transportation.

Since the regulation of new car fuel economies (CAFE standards) is already pushing the market toward smaller and more fuel efficient cars, it is assumed that an increased demand for such cars (Scenario A) only makes the job of meeting the CAFE standards easier and more profitable to the manufacturers. In other words, the increased demand in Scenario A for smaller and more fuel efficient cars is assumed not to affect the supply (in terms of fleet mix and mpg) compared to a situation of less demand for such cars, as in Scenario B.

Table 1: KEY DISTINCTIONS BETWEEN THE TWO BASELINE SCENARIOS (A and B)

ISSUE	SCENARIO A	SCENARIO B
Dominating National Concern	To Conserve Petroleum	To Conserve Energy
General Transportation Policy	More Energy Efficient Vehicles	More Energy Efficient Transportation
Population and Vehicle Fleet Size	More Vehicles per Driver	Less Vehicles per Driver
Travel Pattern and Fleet Mix	Less VKT* per Vehicle	More VKT* per Vehicle
Conventional Vehicle Technology	Same	Same
Prices	Higher Gasoline Prices	Lower Gasoline Prices

* VKT: Average Annual Vehicle Kilometers Traveled.

2. POPULATION AND VEHICLE FLEET SIZE

The projections of the total population and population 16 years and older are identical to the current Series II projections made by the U.S. Bureau of the Census, U.S. Department of Commerce (1)*. Both projections are listed in Table 2.

Table 2: POPULATION FORECASTS (SCENARIO A and B)

July 1 Year	Population Total (x1000)	Population 16 Years and older (x1000)	Licensed Drivers* (x1000)	% of Popula- tion 16 and Older
1960	180,671	121,835	87,253	71.6
1965	194,303	131,542	98,502	74.9
1970	204,878	142,949	111,543	78.0
1975	213,540	155,702	129,815	83.4
1976	215,118	158,324	133,874	84.6
1977	216,745	160,996	137,901	85.7
1978	218,437	163,535	139,005	85.0
1980	222,159	168,335	143,085	85.0
1985	232,880	177,607	150,966	85.0
1990	243,513	185,082	157,320	85.0
1995	252,750	191,139	162,468	85.0
2000	260,378	199,324	169,425	85.0
2005	267,603	207,905	176,719	85.0
2010	275,335	215,392	183,083	85.0

Source: Ref. (1)

The projection of licensed drivers assumes a saturation point for Scenario A and B at 85% of the population 16 years and older, from 1978 (Reference 8, II: pg. 14-2). The number of passenger cars is assumed to saturate for Scenario A in 1985 at 85% and for Scenario B in 1980 at 75% of the number of licensed drivers. The number of light trucks is assumed to saturate for Scenario A in 1990 at 20% and for Scenario B in 1985 at 18% of the number of licensed drivers. All these projections are listed in Tables 3 and 4, and graphically shown in Figure 1.

* Numbers in parentheses designate references listed in Chapter 6.

Table 3: PASSENGER CAR AND LIGHT TRUCK FLEET FORECASTS (SCENARIO A)

July 1 Year	Passenger Cars ¹ (x1000)	% of Drivers	Light Trucks ² (x1000)	% of Drivers	Total Fleet ³ (x1000)
1960	57,103	65.4			
65	68,940	70.0	9,845	10.0	78,785
70	80,449	72.1	13,265	11.9	93,714
75	95,241	73.4	18,610	14.3	113,851
76	97,818	73.1	19,920	14.9	117,738
77	99,904	72.4	21,167	15.3	121,071
1978	102,864	74.0	22,102	15.9	124,965
80	110,891	77.5	24,324	17.0	135,215
85	128,321	85.0	28,684	19.0	157,005
90	133,722	85.0	31,464	20.0	165,186
95	138,098	85.0	32,494	20.0	170,592
2000	144,012	85.0	33,885	20.0	177,897
05	150,211	85.0	35,344	20.0	185,555
2010	155,621	85.0	36,617	20.0	192,237

1. Source: 1960-77, Ref. 3.

2. Assuming that 75% of All Trucks are Light Trucks (1960-77, Ref. 3, p. 44)

3. Not including Heavy Trucks (= 10,000 lbs GVW) and Busses.

Table 4: PASSENGER CAR AND LIGHT TRUCK FLEET FORECAST (SCENARIO B)

July 1 Year	Passenger Cars (x1000)	% of Drivers	Light Trucks (x1000)	% of Drivers	Total Fleet ¹ (x1000)
1978	102,864	74.0	21,963	15.8	124,826
80	107,314	75.0	23,895	16.7	131,209
85	113,224	75.0	27,174	18.0	140,398
90	117,900	75.0	28,318	18.0	146,307
95	121,851	75.0	29,244	18.0	151,095
2000	127,069	75.0	30,497	18.0	157,566
05	132,539	75.0	31,809	18.0	164,349
2010	137,312	75.0	32,955	18.0	170,267

1. Not including Heavy Trucks ($\geq$ 10,000 lbs GVW) and Busses.

Figure 1: Passenger Car and Light Truck Forecast (1960-2010)

3. TRAVEL PATTERNS AND VEHICLE FLEET MIX

As a result of the Mission Analysis, performed in support of the Hybrid Vehicle Potential Assessment Task (see Supplementary Report No. 1), the following five passenger car missions were developed to represent the travel patterns of a little over 90% of the total passenger car fleet:

MISSION	VEHICLE	PRIMARY FUNCTION	MARKET SHARE
I	2 passenger commuter car	Commuting travel	16%*
II	4 passenger family car	Local family travel	30%*
III	6 passenger all purpose car	All family travel	44%*
IV	6 passenger taxi	Taxi	1.0%
V	6 passenger rental car	Vacation rental	0.5%

* The Mission I-III vehicles represent that portion (90%) of the total passenger car fleet which drive 35,000 km or less annually.

Two delivery van missions were developed to represent the travel pattern of light trucks (i.e., trucks with a gross vehicles weight of 10,000 lbs. or less) used for commercial applications. These trucks amount to approximately 45% of the light truck fleet or 35% of the total truck fleet (3):

MISSION	VEHICLE	PRIMARY FUNCTION	LIGHT TRUCK MARKET SHARE
VI	750 kg payload delivery van	Variable route travel	36%
VII	500 kg payload delivery van	Fixed route travel	9%

Each of the Missions I-III were furthermore characterized by three typical travel patterns (percent days/year versus daily travel distance histograms), while only one typical travel pattern was designed for each of the Missions IV and V. Both Missions VI and VII were characterized by two typical travel patterns each. The annual vehicle kilometers traveled (VKT) on each of these 15 typical travel patterns and the summary market share are shown in Table 5.

Table 5: AVERAGE ANNUAL VKT BY MISSION AND TRAVEL PATTERN (1000 KM)

=====						
Passenger Car Missions						
Travel Pattern	I	II	III	IV	V	Market Share ¹

(1)	12.9	9.0	10.6	48.4	48.4	46.5%
(2)	18.7	14.7	16.3	-	-	22.5%
(3)	24.5	21.5	23.1	-	-	22.5%

Market Share ¹	16%	30%	44%	1%	.5%	91.5%

Delivery Van Missions						
Travel Pattern	VI		VII		Market Share ²	

(1)	8.7		11.3		32.5%	
(2)	16.3		22.1		12.5%	

Market Share ²	36%		9%		45%	

1. In percent of passenger car fleet.

2. In percent of light truck fleet (10,000 lbs. GVW or less).

A more detailed breakdown of the market shares for each travel pattern can be calculated from the summary market share figures in Table 5. Such a breakdown is shown in Table 6.

Table 6: FLEET MIX BY MISSION AND TRAVEL PATTERN (% MARKET SHARE)

Passenger Car Missions							
Travel Pattern	I	II	III	IV	V	Other	Sum
(1)	8.0	15.0	22.0	1.0	0.5	8.5	55.0
(2)	4.0	7.5	11.0	-	-	-	22.5
(3)	4.0	7.5	11.0	-	-	-	22.5
Sum	16.0	30.0	44.0	1.0	0.5	8.5	100.0
Delivery Van Missions							
Travel Pattern	VI	VII	Other		Sum		
			Light Trucks				
(1)	26.0	6.5	55.0		87.5		
(2)	10.0	2.5	-		12.5		
Sum	36.0	9.0	55.0		100.0		

Assuming that the annual average VKT for the "Other" passenger car group (8.5% of the total car fleet) is 44,000 km, the market share weighted total fleet average VKT comes to about 18,000 km. This result is consistent with the travel behavior in 1969-70, the base year for the Nationwide Personal Transportation Study (NPTS) done by the U.S. Federal Highway Administration, U.S. Department of Transportation (4,5); and is furthermore consistent with our VKT estimate for the same years (see Table 11). This is to be expected, since the Mission Analysis is primarily based upon NPTS data.

Another consistency check is tabulated in Table 7 and graphically shown in Figure 2. It involves a more detailed comparison with NPTS data on the distribution of cars by annual VKT.

Table 7: DISTRIBUTION OF CARS BY ANNUAL VEHICLE KILOMETERS TRAVELED

Percentile of Passenger Cars (%)	Annual VKT by Mission				Source
	Annual VKT (1000 km)	I (1000 km)	II (1000 km)	III (1000 km)	
2.6	0.8	-	-	-	NPTS*
11.0	4.0	-	-	-	NPTS
31.5	10.5	12.9	9.0	10.6	Table 4
38.1	12.1	-	-	-	NPTS
45.0	13.5	16.0	12.0	13.6	S.R. #1**
58.5	16.2	18.7	14.7	16.3	Table 4
67.5	18.5	21.0	17.0	18.6	S.R. #1
72.7	20.1	-	-	-	NPTS
77.4	22.8	24.5	21.5	23.1	Table 4
81.0	26.0	26.0	25.0	26.6	S.R. #1
83.2	28.2	-	-	-	NPTS
90.8	36.2	-	-	-	NPTS
94.6	44.3	-	-	-	NPTS
95.0	45.0	-	-	-	Table 4

* NPTS: Ref. (4)

** S.R. #1: Supplementary Report #1 (Mission Analysis), HVPA Task

In recent years the average annual VKT for single unit trucks has varied from 2 to 8% below the average annual VKT for passenger cars, according to estimates made by the U.S. Federal Highway Administration (Reference 3, pg. 62). Assuming that the average annual VKT for the "other light trucks" is 21,500 km, the market share weighted annual VKT for the total light truck fleet comes to about 17,000 km, or about 5% below the fleet average annual VKT for passenger cars (18,000 km).

Figure 2: Distribution of Cars by Annual Vehicle Kilometers Traveled (VKT)

By combining the market share figures from Table 6 with the annual VKT figures from Table 5 the percent distribution of total annual fleet VKT of the various market sectors can be calculated. The result of this calculation (VKT share) is tabulated in Table 8. The VKT share shown in this table, as well as the market share and average annual VKT, is assumed to remain constant for both scenarios throughout the whole forecasting period.

The VKT share is utilized in the Impact Analysis to derive representative average (VKT weighted) fuel economy figures (mpg and kwh/km) for the new car fleets, once the most optimal vehicle* with related fuel economy figures has been determined for each market sector and point in time. The VKT weighting technique has been selected because it more accurately reflects the fleet average fuel economy of a vehicle fleet composed of market sectors with distinctively different annual VKT, as assumed in this study.

For example, given a set of new car fleet fuel economy figures as specified in Table 9, the sales-weighted fuel economy would be about 27% too high compared to the VKT-weighted fuel economy.

Table 8: FLEET MIX BY MISSION AND TRAVEL PATTERN (% VKT SHARE)

=====							
Passenger Car Missions							
Travel Pattern	I	II	III	IV	V	Other	Sum
(1)	5.7	7.5	13.0	2.7	1.3	20.8	51.0
(2)	4.2	6.1	10.0	-	-	-	20.3
(3)	5.5	9.0	14.2	-	-	-	28.7
Sum	15.4	22.6	37.2	2.7	1.3	20.8	100.0

Delivery Van Missions							
Travel Pattern	VI	VII	Other			Sum	
			Light Trucks				
(1)	13.3	4.3	69.6			87.2	
(2)	9.6	3.2	-			12.8	
Sum	22.9	7.5	69.6			100.0	
=====							

* Meaning most life-cycle cost effective.

Table 9: HYPOTHETICAL NEW PASSENGER CAR FLEET FUEL ECONOMIES

=====							
Passenger Car Missions							
Travel Pattern		I	II	III	IV	V	Others

(1)	(mpg)	100	80	60	25	20	20
	(kwh/km)	.147	.217	.263	.079	0	0
	(Btu/m)*	2.34	3.27	4.09	4.09	4.09	4.09
(2)	(mpg)	80	60	40	-	-	-
	(kwh/km)	.127	.184	.198	-	-	-
	(Btu/m)*	2.34	3.27	4.09	-	-	-
(3)	(mpg)	60	40	25	-	-	-
	(kwh/km)	.094	.119	.079	-	-	-
	(Btu/m)*	2.34	3.27	4.09	-	-	-

VKT-weighted							
Fleet average FE:		34.9 mpg		.12 kWh/km		3.6 Btu/m	

Sales-weighted							
Fleet average FE:		44.1 mpg		.16 kWh/km		3.6 Btu/m	

* Well-head energy consumption rate. Assuming efficiencies of .95 for the well-head to gas pump path and .33 for the well-head to wall plug path, and 125,000 Btu/gallon.

Well-head energy rate (Btu/km) =

81,762/FE-gasoline (mpg) + 10,348 FE-electricity (kwh/km)

Once the new car or light truck fleet fuel economy has been determined (by VKT weighting) for each point in time (model year), a total fleet fuel economy can be determined for each year by weighting each model year against its respective fraction of the total fleet VKT. Here again, a VKT weighting technique will more accurately reflect the total fleet average fuel economy since newer vehicles seem to be driven more than older vehicles (4,5). The weighting factors for VKT and market share, as well as the average annual VKT, versus vehicle age, as assumed in this study, are tabulated in Table 10.

For example, the market share weighted total fleet fuel economy for year 1985 would be about 6% too low compared to the VKT-weighted total fleet fuel economy given the set of new car fleet fuel economies (EPA Composite mpg) specified in Tables 18 and 19.

Table 10: AVERAGE ANNUAL VKT, MARKET SHARE AND VKT SHARE BY VEHICLE AGE

Vehicle Age (Years)	Passenger Cars			Light Trucks		
	Average VKT* (1000 km)	Market Share** (%)	VKT Share (%)	Average VKT (1000 km)	Market Share (%)	VKT Share (%)
< 1	29.0	8.0	12.7	24.5	7.0	10.1
1 - 2	24.3	11.0	12.7	25.5	9.7	14.6
2 - 3	21.6	10.5	12.4	24.0	9.2	13.0
3 - 4	19.6	10.1	10.9	21.0	8.7	10.8
4 - 5	18.2	9.7	9.7	18.9	8.0	8.9
5 - 6	16.9	9.3	8.6	17.4	7.1	7.3
6 - 7	15.8	8.9	7.7	16.3	6.3	6.0
7 - 8	14.8	7.5	6.1	15.3	5.6	5.0
8 - 9	14.0	6.0	4.6	14.3	5.1	4.3
9 - 10	13.4	5.0	3.7	13.4	4.6	3.6
10 - 11	12.7	4.0	2.8	12.5	4.1	3.0
11 - 12	12.2	3.0	2.0	11.7	3.6	2.5
12 - 13	11.7	2.0	1.3	10.8	3.2	2.0
13 - 14	11.3	1.2	.7	10.0	2.8	1.6
14 - 15	10.8	1.0	.6	9.3	2.5	1.4
15 - 16	10.5	.8	.5	8.7	2.2	1.1
> 16	10.1	2.0	1.0	7.9	10.3	4.8
Total		100.0	100.0		100.0	100.0

* Source: Ref. (5), Page 97

** Source: Ref. (3), Page 32

As an indicator of overall changes in the travel pattern over time, the annual fleet average VKT has been selected. One forecast of the annual fleet average VKT has been made for each baseline scenario (A and B), both indicating a saturation level to be reached in year 2000. These forecasts, shown in Table 11 and Figure 3, assumes an overall modest growth in VKT similar to that of the early 60-ties. The more dramatic increases in VKT from 1965-73 were probably motivated to a great extent by the equally dramatic expansion of the highway system, thus representing a situation which is assumed to be non-reoccurring. The average annual VKT for light trucks is assumed to remain 1,000 km below the VKT for cars, as it has in recent years.

Table 11: AVERAGE ANNUAL VKT FORECASTS

Year	SCENARIO A			SCENARIO B		
	Passenger Cars		Light Trucks	Passenger Cars		Light Trucks
	VKT (km)	% Change*	VKT (km)	VKT (km)	% Change*	VKT (km)
1960	16,591					
1965	16,642	+ 0.3				
1966	16,876	+ 2.0				
67	17,104	+ 4.0				
68	17,640	+ 7.5				
69	17,954	+ 8.0				
70	18,123	+ 8.9				
1971	18,563	+10.0				
72	18,484	+ 8.1				
73	18,778	+ 6.5				
74	17,050	- 5.0				
75	17,210	- 5.0				
					Same as Scenario A	
1980	17,898	+ 4.0	16,898	18,071	+ 5.0	17,071
1985	18,435	+ 3.0	17,435	18,793	+ 4.0	17,793
1990	18,804	+ 2.0	17,804	19,357	+ 3.0	18,357
1995	18,992	+ 1.0	17,992	19,744	+ 2.0	18,744
2000	19,087	+ 0.5	18,087	19,942	+ 1.0	18,942
2005	19,087	0.0	18,087	19,942	0.0	18,942
2010	19,087	0.0	18,087	19,942	0.0	18,942

* % changes from 5-years ago.

Figure 3: Fleet Average Annual VKT Forecasts (1960-2010)

4. CONVENTIONAL VEHICLE TECHNOLOGY (OTTO BASELINE)

As a point of reference, a conventional vehicle technology baseline (Otto-baseline) forecast for the new car fleets has been developed, assuming no hybrid or electric vehicle market penetration. The basic assumptions for this projection are:

- (A) No vehicle performance degradation over time.
- (B) A weight-reduction schedule as indicated in Figure 4 for the 1976-85 model year changes, with only moderate weight-reduction after 1985 as follows:
 - 1985-1990: + 15%
 - 1985-1995: + 25%
 - 1985-2000: + 30%
- (C) A moderate fleet mix shift toward smaller cars from 1976 - 85.
- (D) An improvement in fuel economy (mpg), due to technological changes other than weight reduction (and their gradually increased market penetration), as follows:
 - 1977-1985: + 18.5%, reference (6)
 - 1977-1990: + 21.0%
 - 1977-1995: + 23.0%
 - 1977-2000: + 25.0%
- (E) No weight-reduction or fuel economy improvements after year 2000, and no shift in fleet mix after 1985.
- (F) Domestic new car fleet mpg (sales weighted) at least as high as the CAFE-standards.

The relationship between weight reduction and vehicle curb weight is shown on Figure 4. The data points represent a recent General Motors weight reduction schedule for 13 typical GM-cars over the time period from 1976-85 (6). A logarithmic curve fit for these data points (except the outlying Corvette data), equate weight reduction (WR) to 1976 curb weight (CW) as follows:

$$(Eq. 1) \quad WR_{1976-1985}(kg) = 461.63 \ln(CW_{1976}(kg)) - 3039.2$$

The assumed weight reduction for year 2000, of 30% above the 1985 weight reduction, corresponds to two published estimates of the potential (practicable) weight reduction on midsize cars (7) and large cars (8), utilizing innovative technology. Based on the weight reduction scheme

outlined in assumption (B), mentioned above, the following weight reduction forecasts have been derived for model years 1990, 1995, and 2000:

$$(Eq. 2) \quad WR_{1976-1990}(kg) = 530.87 \ln(CW_{1976}(kg)) - 3495.1$$

$$(Eq. 3) \quad WR_{1976-1995}(kg) = 577.04 \ln(CW_{1976}(kg)) - 3799.0$$

$$(Eq. 4) \quad WR_{1976-2000}(kg) = 600.12 \ln(CW_{1976}(kg)) - 3951.0$$

Figure 4: Weight Reduction Forecasts (Otto Baseline, 1985-2000)

The historical relationship between weight class, average inertia weight* (IW), average fuel economy (FE), and sales distribution of the two base model years (1976 and 1977) are tabulated in Tables 12 and 13 for five typical weight classes.

* NOTE: Inertia Weight = Curb weight + 300 lbs.

Table 12: AVERAGE INERTIA WEIGHT (IW), FUEL ECONOMY (FE) AND SALES
FOR MODEL YEAR 1976

Weight-class	Average IW		Average FE (mpg)	Fleet Mix		
	(kg)	(lbs)		USA (%)	Imports (%)	Total (%)
Small	1006	2218	29.1	1.1	6.8	7.9
Subcompact	1175	2590	25.4	2.1	3.9	6.0
Compact	1476	3253	21.0	22.5	4.6	27.1
Full size	1955	4311	16.1	37.0	0.4	37.4
Large	2347	5175	14.1	21.6	0.0	21.6
Total Sales (%)				84.3	15.7	100.0
Fleet Average Fuel Economy (sales weighted mpg)				16.8	24.9	17.7

Source: Reference (9), Appendix A; and Reference (10)

Table 13: AVERAGE INERTIA WEIGHT (IW), FUEL ECONOMY (FE) AND SALES
FOR MODEL YEAR 1977

Weight Class	Average IW		Average FE (mpg)	Fleet Mix		
	(kg)	(lbs)		USA (%)	Imports (%)	Total (%)
Small	1005	2216	32.1			8.8
Subcompact	1195	2635	26.7			6.8
Compact	1480	3262	21.8			16.3
Full size	1926	4246	17.3			57.7
Large	2310	5093	13.9			10.4
Total Sales (%)				85.6	14.4	100.0
Fleet Average Fuel Economy (sales weighted mpg)				17.7	27.3	18.7

Source: Reference (9), Appendix A; and Reference (10)

A power curve fit of the fuel economy data in reference (9), Appendix A, for model year 1977 cars equate the fuel economy (FE) to the Inertia Weight (IW) as follows:

$$(Eq. 5) \quad FE_{1977}(\text{mpg}) = 32,357 (IW_{1977}(\text{kg}))^{-.9998}$$

Based on the fuel economy improvement schedule outlines in point (D) of the basic assumptions for the Otto-baseline (see page 15), similar equations have been derived for model year 1990, 1995, and 2000 cars, as follows:

$$(Eq. 6) \quad FE_{1985}(\text{mpg}) = 38,343 (IW_{1985}(\text{kg}))^{-.9998}$$

$$(Eq. 7) \quad FE_{1990}(\text{mpg}) = 39,152 (IW_{1990}(\text{kg}))^{-.9998}$$

$$(Eq. 8) \quad FE_{1995}(\text{mpg}) = 39,799 (IW_{1995}(\text{kg}))^{-.9998}$$

$$(Eq. 9) \quad FE_{2000}(\text{mpg}) = 40,446 (IW_{2000}(\text{kg}))^{-.9998}$$

The detailed forecasts for model year 1985, 1990, 1995 and 2000 and after are tabulated in Tables 14-17; based on weight reductions as specified in Equations 1-4, fuel economies as specified in Equations 6-9, and a moderate shift in fleet mix towards smaller cars compared to the model year 1976 and 1977 fleet mixes.

The forecasts for year 1985 and 2000 are graphically shown in Figure 5, together with the two base years 1976 and 1977.

Table 18 contains historical data on the New Car Fleet Fuel Economies for model year 1954-78, in terms of EPA composite mpg as well as an adjusted on-road mpg, which is somewhat lower than the EPA composite mpg (see footnote 3 in Table 18). The forecasts of the New Car Fleet Fuel Economies for model year 1979-2010 is based on Tables 14-17 with interpolated data points for the remaining model years, and tabulated in Table 19.

The total passenger car fleet average fuel economies (market and VKT weighted) have been calculated for year 1970-2010 (based on Table 10, 18 and 19) and are shown in Table 20 and Figure 6.

The new light truck fleet fuel economics and their on-road mpg values are estimated assuming a 30% reduction in the EPA composite mpg compared to the new car fleet fuel economics and a conversion to on-road mpg equal to that of the passenger cars (see footnote 3, table 18). These estimates, for year

1970 - 2010, are tabulated in Table 21 together with the resulting total light truck fleet fuel economics (assuming the market and VKT share distribution versus age for light trucks in Table 10).

As the bottom line of the Conventional Vehicle Technology Forecasts the annual petroleum consumption has been calculated, assuming the passenger car fleet size forecasts in Tables 3 and 4, the average annual VKT forecasts in Table 11, and the total fleet average (VKT weighted, on-road) fuel economy forecast in Tables 20 and 21. This forecast is shown in Figure 7, and tabulated in Table 22 for both passenger cars and trucks.

Table 14: DETAILED CONVENTIONAL VEHICLE TECHNOLOGY FORECAST
FOR MODEL YEAR 1985

Weight Class	Average Inertia Weight*		Average Fuel Economy** (mpg)	USA (%)	Fleet Mix	
	(kg)	(lbs)			Imports (%)	Total (%)
Small	930	2050	41.5	5	6	11
Subcompact	1010	2225	38.0	10	4	14
Compact	1200	2650	32.0	25	5	30
Full Size	1530	3375	25.0	29	1	30
Large	1840	4050	21.0	15	0	15
Total Sales (%)				84	16	100
Fleet Average Fuel Economy (sales weighted mpg)				27.6	35.9	28.7

* $IW_{1985}(kg) = IW_{1976}(kg) - 461.63 \ln(CW_{1976}(kg)) + 3039.2$
(rounded off to nearest 10 kg or 25 lbs)

** See Eq. 6 (Rounded off to nearest half mpg)

Table 15: DETAILED CONVENTIONAL VEHICLE TECHNOLOGY FORECAST
FOR MODEL YEAR 1990

Weight Class	Average Inertia Weight*		Average Fuel Economy** (mpg)	USA (%)	Fleet Mix	
	(kg)	(lbs)			Imports (%)	Total (%)
Small	910	2000	43.0	5	6	11
Subcompact	980	2150	40.0	10	4	14
Compact	1150	2525	34.0	25	5	30
Full Size	1470	3250	26.5	29	1	30
Large	1750	3850	22.5	15	0	15
Total Sales (%)				84	16	100
Fleet Average Fuel Economy (sales weighted mpg)				29.3	37.7	30.4

* $IW_{1990}(kg) = IW_{1976}(kg) - 530.87 \ln(CW_{1976}(kg)) + 3495.1$
(Rounded off to the nearest 10 kg or 25 lbs)

** See Eq. 7 (Rounded off to nearest half mpg)

Table 16: DETAILED CONVENTIONAL VEHICLE TECHNOLOGY FORECAST
FOR MODEL YEAR 1995

Weight Class	Average Inertia Weight*		Average Fuel Economy** (mpg)	USA (%)	Fleet Mix Imports		Total (%)
	(kg)	(lbs)			(%)		
Small	900	1975	44.5	5	6		11
Subcompact	970	2150	41.0	10	4		14
Compact	1120	2475	35.5	25	5		30
Full Size	1420	3125	28.0	29	1		30
Large	1700	3750	23.5	15	0		15
Total Sales (%)				84	16		100
Fleet Average Fuel Economy (sales weighted mpg)				30.7	39.1		31.8

* $IW_{1995}(kg) = IW_{1976}(kg) - 577.04 \ln(CW_{1976}(kg)) - 3799.0$
(Rounded off to nearest 10 kg or 25 lbs)

** See Eq. 8 (Rounded off to nearest half mpg)

Table 17: DETAILED CONVENTIONAL VEHICLE TECHNOLOGY FORECAST
FOR MODEL YEAR 2000 AND AFTER

Weight Class	Average Inertia Weight*		Average Fuel Economy** (mpg)	USA (%)	Fleet Mix Imports		Total (%)
	(kg)	(lbs)			(%)		
Small	890	1950	45.5	5	6		11
Subcompact	960	2125	42.0	10	4		14
Compact	1110	2450	36.5	25	5		30
Full Size	1400	3075	30.0	29	1		30
Large	1680	3700	24.0	15	0		15
Total Sales (%)				84	16		100
Fleet Average Fuel Economy (sales weighted mpg)				32.0	40.3		33.1

* $IW_{2000}(kg) = IW_{1976}(kg) - 600.12 \ln(CW_{1976}(kg)) + 3951.0$
(Rounded off to nearest 10 kg or 25 lbs)

** See Eq. 9 (Rounded off to nearest half mpg)

Figure 5: Fuel Economy Forecast (Otto Baseline, 1985-2000)

Table 18: SUMMARY NEW PASSENGER CAR FLEET FUEL ECONOMIES (1954-78)

Model Year	Percent Sales ¹		New Car Fleet FE ²			New Car Fleet FE ³
	USA (%)	Imports (%)	USA (EPA Composite mpg)	Imports (EPA Composite mpg)	Average (EPA Composite mpg)	Average (On-Road mpg)
1954	99.4	0.6	16.0	37.0	16.1	14.2
55	99.2	0.8	16.0	37.0	16.1	14.3
1956	98.4	1.6	15.9	35.6	16.0	14.2
57	96.6	3.4	15.8	34.3	16.1	14.3
58	91.9	8.1	15.7	33.0	16.4	14.5
59	89.9	10.1	15.6	31.7	16.4	14.5
60	92.5	7.5	15.5	30.4	16.1	14.3
1961	93.6	6.4	15.4	30.7	15.9	14.1
62	95.2	4.8	15.4	30.9	15.8	14.0
63	95.0	5.0	15.4	31.3	15.8	14.0
64	94.0	6.0	15.4	31.7	15.9	14.1
65	93.9	6.1	15.4	32.1	15.9	14.1
1966	92.8	7.2	15.0	30.8	15.6	13.9
67	90.8	9.2	14.6	29.6	15.3	13.7
68	89.3	10.7	14.2	28.4	15.0	13.5
69	88.3	11.7	14.1	27.9	15.0	13.5
70	84.7	15.3	14.1	27.2	15.2	13.6
1971	84.7	15.3	13.7	24.0	14.7	13.3
72	85.2	14.8	13.6	22.5	14.4	13.1
73	84.6	15.4	13.3	22.6	14.2	12.9
74	84.1	15.9	12.8	21.5	13.7	12.6
75	87.9	12.1	14.9	24.5	15.6	13.9
1976	84.3	15.7	16.8	24.9	17.7	15.4
77	85.6	14.4	17.7	27.3	18.6	16.0
78	84.6	15.4	18.7	26.8	19.6	16.7

- Source: 1955-74; Motor Vehicle Manufacturers Association, Ref. (2) & (3)
1975-78; EPA, Ref. (9).
- Source: 1955-74; DOE, Ref. (10) for USA and Imported FE only.
1975-78; EPA, Ref. (9).
- Assuming the following relationship between the EPA composite mpg and the on-road mpg (based on Ref. (11)):

$$\text{FE (on-road mpg)} = .71 \text{ FE (EPA composite mpg)} + 2.83.$$

Table 19: SUMMARY NEW PASSENGER CAR FLEET FUEL ECONOMIES (1979-2010)

Model Year	Percent Sales		New Car Fleet FE			New Car Fleet FE
	USA (%)	Imports (%)	USA (EPA Composite mpg)	Imports (EPA Composite mpg)	Average (mpg)	Average (On-Road mpg)
1979	84	16	19.6	27.7	20.6	17.4
80	84	16	20.5	28.6	21.5	18.1
1981	84	16	22.4	30.5	23.4	19.4
82	--	--	24.3	32.4	25.3	20.8
83	--	--	26.2	34.4	27.2	22.2
84	--	--	27.1	35.4	28.2	22.8
85	84	16	27.6	35.9	28.7	23.2
1986	--	--	28.0	36.3	29.1	23.5
87	--	--	28.4	36.7	29.5	23.8
88	--	--	28.7	37.1	29.8	24.0
89	--	--	29.0	37.4	30.1	24.2
90	84	16	29.3	37.7	30.4	24.4
1991	--	--	29.6	38.0	30.7	24.6
92	--	--	29.9	38.3	31.0	24.8
93	--	--	30.2	38.6	31.3	25.0
94	--	--	30.5	38.9	31.6	25.3
95	84	16	30.7	39.1	31.8	25.4
1996	--	--	31.0	39.4	32.1	25.6
97	--	--	31.3	39.7	32.4	25.8
98	--	--	31.6	39.9	32.7	26.0
99	--	--	31.8	40.1	32.9	26.2
2000	84	16	32.0	40.3	33.1	26.3
2005	84	16	32.0	40.3	33.1	26.3
2010	84	16	32.0	40.3	33.1	26.3

Table 20: TOTAL PASSENGER CAR FLEET AVERAGE FUEL ECONOMIES (1970-2000)

Year	Market Shares Weighted		VKT Weighted	
	(EPA Comp. mpg)	(On-Road mpg)	(EPA Comp. mpg)	(On-Road mpg)
1970	15.6	13.9	15.5	13.8
1971	15.5	13.8	15.3	13.7
72	15.3	13.7	15.2	13.6
73	15.1	13.6	15.0	13.5
74	14.9	13.5	14.8	13.3
75	14.9	13.4	14.8	13.4
1976	15.1	13.5	15.1	13.6
77	15.3	13.7	15.5	13.9
78	15.7	14.0	16.1	14.3
79	16.2	14.3	16.7	14.7
80	16.7	14.8	17.3	15.2
1981	17.4	15.3	18.2	15.8
82	18.3	15.9	19.2	16.5
83	19.2	16.6	20.3	17.3
84	20.3	17.3	21.5	18.2
85	21.4	18.1	22.7	19.0
1986	22.5	18.9	23.8	19.8
87	23.6	19.7	24.9	20.6
88	24.6	20.4	25.9	21.3
89	25.6	21.1	26.7	21.9
90	26.5	21.7	27.5	22.4
1991	27.4	22.3	28.3	23.0
92	28.2	22.9	28.9	23.4
93	28.8	23.3	29.5	23.8
94	29.4	23.7	29.9	24.1
95	29.9	24.0	30.3	24.4
1996	30.3	24.3	30.7	24.6
97	30.7	24.6	31.1	24.9
98	31.1	24.9	31.4	25.1
99	31.4	25.1	31.7	25.3
2000	31.7	25.3	32.0	25.5
2001				25.7
02				25.8
03				25.9
04				26.0
05				26.1
2006				26.2
07				26.2
08				26.2
09				26.3
2010				26.3

Table 21: LIGHT TRUCK FLEET FUEL ECONOMIES (1970-2010)

Year	New Fleet (EPA Comp. mpg)	New Fleet (On-Road mpg)	Total Fleet Market Weighted (EPA Comp. mpg)	Total Fleet VKT Weighted (On-Road mpg)
1970	10.6	10.4		10.5
1971	10.3	10.1		10.5
72	10.1	10.0		10.4
73	9.9	9.9		10.3
74	9.6	9.6		10.2
75	10.9	10.6		10.12
1976	12.4	11.6		10.3
77	13.0	12.1		10.6
78	13.7	12.6		10.8
79	14.4	13.1		11.1
80	15.1	13.5		11.5
1981	16.4	14.5		11.8
82	17.7	15.4		12.3
83	19.0	16.3		12.8
84	19.7	16.8		13.3
85	20.1	17.1		13.8
1986	20.4	17.3		14.3
87	20.7	17.5		14.7
88	20.9	17.6		15.1
89	21.1	17.8		15.5
90	21.3	17.9		15.9
1991	21.5	18.1		16.3
92	21.7	18.2		16.7
93	21.9	18.4		17.0
94	22.1	18.5		17.3
95	22.3	18.6		17.5
1996	22.5	18.8		17.8
97	22.7	18.9		18.0
98	22.9	19.1		18.2
99	23.0	19.2		18.4
2000	23.2	19.3		18.6
2001	23.2	19.3		18.7
02	23.2	19.3		18.8
03	23.2	19.3		18.9
04	23.2	19.3		19.0
05	23.2	19.3		19.1
2006	23.2	19.3		19.1
07	23.2	19.3		19.1
08	23.2	19.3		19.2
09	23.2	19.3		19.2
10	23.2	19.3		19.2

Figure 6: Fleet Average Fuel Economy Forecast (Otto Baseline, 1970-2010)

Table 22: ANNUAL PETROLEUM CONSUMPTION FORECAST (OTTO BASELINE, 1960-2000)

	Scenario A				Scenario B			
	Pass. Cars		Light Trucks		Pass. Cars		Light Trucks	
	(Quads) (10^6 gal)		(Quads) (10^6 gal)		(Quads) (10^6 gal)		(Quads) (10^6 gal)	
1960	5.15	(41,169)						
65	6.28	(50,206)	1.11	(8,860)	Same as Scenario A			
70	8.21	(65,649)	1.68	(13,442)				
75	9.50	(76,010)	2.30	(18,373)				
1980	10.40	(83,217)	2.78	(22,209)	9.91	(79,279)	2.76	(22,041)
85	9.67	(77,366)	2.81	(22,519)	8.70	(69,590)	2.72	(21,771)
90	8.72	(69,754)	2.74	(21,893)	7.92	(63,358)	2.54	(20,316)
95	8.35	(66,793)	2.59	(20,759)	7.66	(61,269)	2.43	(19,464)
2000	8.37	(66,982)	2.56	(20,475)	7.72	(61,749)	2.41	(19,299)
05	8.53	(68,259)	2.60	(20,798)	7.87	(62,927)	2.45	(19,602)
2010	8.77	(70,180)	2.68	(21,434)	8.09	(64,697)	2.53	(20,203)

Figure 7: Annual Petroleum Consumption Forecast (Otto Baseline, 1960-2010)

5. BATTERY TECHNOLOGY

The energy and power ratings for the batteries utilized in the Hybrid Vehicle Potential Assessment Study, as well as the cost ratings in 1978 \$, are not assumed to change with time, but reflect in principle what can be expected in 1985 (Table 23).

The projected cycle life, on the other hand, is assumed to improve with time as shown in Table 24. All of these numbers are relatively optimistic; i.e. better than recent battery manufacturers estimates and about equal to the DOE battery goals, and projections made in reference 12.

Table 23: ASSUMED BATTERY CHARACTERISTICS

Battery Type	Lead-acid	Ni-Zn	Na-S
Energy Density C3-rate (Wh/kg)	44	77	120
Power Density	(see S.R. #3.p. - Ragoni Plots)		
Manufacturing Cost (1978 \$/kWh)	40	60	50
Initial User Cost (1978 \$/kWh)	80	120	100
After Market Cost (1978 \$/kWh)	92	138	115

Table 24: BATTERY CYCLE LIFE PROJECTIONS

Cycle Life	Lead-acid	Ni-Zn	Na-S
1980	500	N/A*	N/A
1985	1000	500	N/A
1990	1000	1000	N/A
1995	1000	1000	1000
2000	1000	1000	1000
2005	1000	1000	1000
2010	1000	1000	1000

*not available

6. FUEL PRICES

It is first of all assumed that the future fuel prices for gasoline and diesel will be somewhat higher in the Petroleum Conservation Scenario (A) than in the Energy Conservation Scenario (B). For Scenario B it is furthermore assumed that the future average cost of gasoline per km will stay constant at the 1978 level, in terms of real dollars. The 1978 fleet average Fuel Economy of 14.3 mpg (VKT weighted, On-Road mpg; see Table 20), and the 1978 gasoline price of 72.0 ¢/gallon, defines the fixed gasoline cost per km as 2.13 cents/km in 1978 \$ for Scenario B.

Scenario A assumes a linearly increasing gasoline price of plus ¢/gallon per year from 1979, which for 1978-85 is very close to a fixed gasoline cost per km scenario similar to scenario B, but based upon the fuel economy projections for the new car fleet rather than the total car fleet.

The future diesel prices are assumed to stay, as they have in recent years, 7% below the gasoline prices. Even though the gasoline and diesel price projections are higher than generally expected, they are still judged to be reasonable, when viewed as a set of upper bound price projections. The selection of these upper bounds rather than a set of medium (or most likely) price projections is primarily based upon the following two considerations:

- The cost effectiveness of hybrid (and electric) vehicles and hence their potential market penetration is very sensitive to the gasoline and diesel prices.
- The scenarios developed in this report are used to assess the potential impact rather than the most likely impact of hybrid vehicles.

The future electricity prices basically follow a recent DRI projection of moderate growth. All of these fuel price projections (in 1978 cents) are tabulated in Table 25. The gasoline price forecast is also shown in Figure 8.

Table 25: FUEL PRICE FORECAST, 1960-2010 (1978 cents)

Year	Scenario A		Scenario B		Scenario A & B Electricity* (c/kwh)
	Gasoline (c/gal)	Diesel (c/gal)	Gasoline (c/gal)	Diesel (c/gal)	
1960	66.5	--			
1965	61.3	--	Same as Scenario A		
1970	57.3	--			
1975	66.0	--			
1978	72.0	67.0	72.0	67.0	4.2
79	75.0	69.8	74.0	68.9	4.1
80	80.0	74.4	76.6	71.2	4.0
1981	85.0	79.1	79.6	74.0	4.0
82	90.0	83.7	83.1	77.3	4.1
83	95.0	88.4	87.1	81.0	4.1
84	100.0	93.0	91.7	85.3	4.2
85	105.0	97.7	95.7	89.0	4.2
1986	110.0	102.3	99.7	92.8	4.3
87	115.0	107.0	103.8	96.5	4.3
88	120.0	111.6	107.3	99.8	4.4
89	125.0	116.3	110.3	102.6	4.4
90	130.0	120.9	112.8	104.9	4.5
1991	135.0	125.6	115.9	107.7	4.5
92	140.0	130.2	117.9	109.6	4.6
93	145.0	134.9	119.9	111.5	4.6
94	150.0	139.5	121.4	112.9	4.7
95	155.0	144.2	122.9	114.3	4.7
1996	160.0	148.8	123.9	115.2	4.8
97	165.0	153.5	125.4	116.6	4.8
98	170.0	158.1	126.4	117.6	4.9
99	175.0	162.8	127.4	118.5	4.9
2000	180.0	167.4	128.4	119.4	5.0
2001	185.0	172.1	129.4	120.3	5.0
02	190.0	176.7	129.9	120.8	5.1
03	195.0	181.4	130.4	121.3	5.1
04	200.0	186.0	130.9	121.7	5.2
05	200.0	186.0	131.4	122.2	5.2
2006	200.0	186.0	131.9	122.7	5.3
07	200.0	186.0	131.9	122.7	5.3
08	200.0	186.0	131.9	122.7	5.4
09	200.0	186.0	132.4	123.2	5.4
2010	200.0	186.0	132.4	123.2	5.5

* Source: DRI projection for 1978, 80, 85, and 90.

Figure 8: Gasoline Price Forecasts (1960-2010)

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