Title
Evaluation Of Potential Hybrid Electric Vehicle Applications: Vol I

Author
Gris, Arturo E.

Publication Date
1991

Program on Advanced Technology for the Highway
INSTITUTE OF TRANSPORTATION STUDIES
UNIVERSITY OF CALIFORNIA AT BERKELEY

Evaluation of Potential Hybrid Electric Vehicle Applications
Volume I

Arturo E. Gris

PATH Research Report
UCB-ITS-PRR-91-4

This work was performed as part of the Program on Advanced Technology for the Highway (PATH) at the Institute of Transportation Studies, University of California, Berkeley, under the sponsorship of Chevron Research Company.

ISSN1055-1425

EVALUATION OF POTENTIAL HYBRID ELECTRIC VEHICLE APPLICATIONS
VOLUME I

Arturo E. Gris

University of California
Berkeley, CA 94720

ACKNOWLEDGEMENTS

This work was performed as part of the Program on Advanced Technology for the Highway (PATH) at the Institute of Transportation Studies, University of California, Berkeley, under the sponsorship of the Chevron Research Company and the technical supervision of Dr. Steven Shladover. The author would like to thank the sponsors for their support, and would also like to thank Dr. Kenneth Heitner and Mr. Kenneth Barber of the U.S. Department of Energy, Mr. John Free1 of Chevron Research Company, and Dr. John Reuyl of Stanford University for their comments on an earlier draft of this report. This report represents the views of the author who is responsible for the facts and the accuracy of the data presented herein. This paper does not constitute a standard, specification, or regulation.

ABSTRACT

Electric and hybrid vehicles possess characteristics that make them favorable for different applications. The purpose of this report is to identify potentially promising market segments for electric and hybrid vehicle technologies.

Different market segments are represented by driving scenarios and representative vehicles (automobile, mini van, van or bus). Each driving scenario combines SAE J227a cycles and constant velocity travel, with some portions of the cycles being on specified grades. A simulation program is used to calculate the energy required for each driving scenario. The energy to provide air conditioning is calculated based on the air conditioning power demand for the different vehicles. The power rating required for each vehicle is chosen to satisfy the performance demanded by the driving scenario, an acceleration requirement and a top cruise speed requirement.

Each configuration, electric and series hybrid, is evaluated with sodium sulfur, nickel iron, nickel zinc, lead acid and lead acid gel cell batteries for the different driving scenarios without and with air conditioning. Limitations, advantages and disadvantages of each design are then discussed.

SUMMARY

Different market segments are represented by the following driving scenarios and vehicles:

1) Residential postal scenario, mail delivery vehicle.
2) Small delivery scenario, mini van.
3) Long delivery scenario (for two different maximum delivery ranges), van.
4) City scenario, automobile.
5) Large metropolis scenario (for two different maximum driving ranges), automobile.
6) Intercity travel, automobile.
7) Local bus.
8) Intercity travel, bus.

Each driving scenario combines SAE J227a cycles and constant velocity travel. The energy requirements are calculated using a simulation program. The power requirement for each vehicle is selected to satisfy the driving scenario, an acceleration requirement and a top speed requirement.

Five battery technologies are considered: sodium-sulfur, nickel-iron, nickel-zinc, lead-acid and lead-acid gel cell. All the batteries are tried in electric and series hybrid versions for each of the driving scenarios. For the series hybrid, an internal combustion engine-electric generator set is used. The design approach selected for the hybrid vehicles is to size the battery and range extender so that the energy and power requirements are met exactly (i.e. without any extra energy or power).

The energy requirement to provide air conditioning is calculated based on the power demand of the air conditioner for each of the vehicles. The vehicle designs with air conditioning are designed to still satisfy driving range of the previously mentioned driving scenarios.

In general, electric vehicles are the best options for short range driving scenarios where the battery has to be sized to meet the power requirement, because the use of a range extender for those driving scenarios produces no benefits. On the other hand, range extenders proved to be extremely helpful for long-range driving scenarios by increasing the range of the vehicle and decreasing the amount of battery required.

Air conditioning requires a large amount of additional energy, making it almost mandatory to have an additional energy source other than the battery. Unless an extremely short driving range is acceptable, hybrid vehicles are the best and only possible alternative.

More detailed results, including the recommended battery technologies and engine-generator power ratings for each driving scenario can be found summarized in the Conclusions section.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Two factors make electric and hybrid vehicles attractive: first, they can reduce the transportation dependency on fossil fuels; and second, they can help reduce air pollution by producing less or no mobile source emissions during operation.

From the point of view of purely reducing fossil fuel usage and mobile source emissions, electric vehicles would be better than hybrid vehicles. But with the current and foreseen battery technology and reasonable constraints on weight and size of the battery, electric vehicles have the problem that only limited range can be achieved. Hybrid vehicles can solve this problem in certain applications by increasing the vehicle range and reducing the amount of battery needed. This counteracts the lesser effect that they have on reducing fossil fuel usage and mobile source vehicle emissions, while significantly expanding the potential market for electric vehicles.

This report will cover:

- The driving scenarios developed to represent each market segment.
- Energy and power requirements for each scenario.
- Designs that are best suited for each scenario (the designs concentrated on the battery sizing for electric vehicles and on the battery and range extender sizing for hybrid vehicles).
- Requirements to provide air conditioning.
- Designs with air conditioning that are best suited for each scenario.

For the hybrid vehicle designs, the series hybrid configuration was selected. It is important to note that earlier studies [1][2] found that the parallel hybrid configuration was more efficient in terms of energy consumption than the series configuration. This is due to the fact that in the parallel configuration the energy from the fuel only has to go through one conversion, while in the series configuration the energy has to go through the inefficiencies of two energy conversions in series. Nevertheless, recent studies [3] favor the series configuration for its simplicity and the fact that it requires the least amount of changes to an already existing electric vehicle (i.e., no clutches or other mechanical complications). Another factor to favor the series configuration is the recent improvement obtained in the efficiency of the individual components, making the fuel consumption difference between series and parallel configurations minimal.

The design approach selected for the hybrid vehicles is to size the battery and range extender in such a way that the energy and power requirements are met exactly (i.e. without any extra energy or power). An alternate approach is to size the range extender to supply the average power required in the driving scenario and the battery to satisfy peak power demands. The former approach was selected because it favors smaller engine-generators and the use of more battery, therefore producing designs that would run cleaner (more details can be found in Section 8).

When the electric and series hybrid vehicles are compared, the one component that has been added to the latter is the engine-generator set, which is referred to hereafter as the range extender (RX) due to its ability to increase the range of the vehicle.

Of course, the energy from the RX is produced at the cost of some emissions, but its emissions could be lower than those of a standard I.C. vehicle because the RX has a small engine running at constant speed, while the normal I.C. engine runs over a wide range of speeds. The constant speed of the RX can be set to the most efficient operational speed.

2. GENERAL BACKGROUND

Electric vehicles use electrical energy through an energy converter to propel the vehicle. Their energy is usually stored in a battery and the energy converter is an electric motor.

Hybrid vehicles use two or more sources or stores of energy to propel the vehicle. In the series hybrid configuration, the hybrid vehicle only has one energy converter capable of directly propelling the vehicle. In the parallel hybrid configuration, two or more energy converters can propel the vehicle. For example, a hybrid vehicle that uses gasoline and a battery as sources of energy in the series configuration would use an electric motor to propel the vehicle. The electric energy would come from the battery or from the gasoline after passing through a combustion engine-electric generator set. The parallel configuration, on the other hand, would use both the electric motor and the internal combustion engine to propel the vehicle directly. In the parallel configuration, clutches are usually required to connect the electric motor and the I.C. engine to the drive train.

A new type of hybrid vehicle configuration is the series/parallel. In this configuration the vehicle has switches and clutches to select whether it runs in a series or parallel configuration.

As mentioned earlier, the series hybrid configuration was selected for the hybrid designs in this report.

3. ANALYSIS APPROACH

3.1 DRIVING SCENARIOS

Driving scenarios were developed for different market segments. Each scenario is composed of a combination of SAE J227a cycles and constant velocity travel. Grades were superimposed on them for a certain percent of the distance to represent operations on hills. A top speed requirement (on flat surface) and an acceleration requirement were placed on the vehicles used for each driving scenario to try to ensure that the vehicles would have performance acceptable to potential customers. Since vehicles have to be designed to satisfy the requirements of the maximum desired range, maximum range was a vital element of each driving scenario description.

The complete descriptions of the driving scenarios are next, followed by a summary of the driving scenarios in Tables 1.a, l.b, 1.c and Table 2.

3.1.1 Driving Scenario Descriptions

(I) **Residential Postal or Milk Delivery Truck**

Range: 10 miles to travel to the delivery area plus 3 miles in the delivery area, for a total range of 13 miles.

Speed: 30 mi/h to travel to the delivery area. SAE "A" cycle in the delivery area. The cruise speed of the SAE "A" cycle is 10 mi/h.

Grades: Should handle 6% hills, in the worst scenario for 50% of the distance.

Top speed: Maximum velocity of at least 45 mi/h for traffic compatibility.

Comments: 5 stops per block. 3 hour driving scenario.

(II) **Small Local Delivery Mini Van or Local Bus**

Range (two options): (A. Mini Van) 40 miles to travel to the delivery area plus 60 miles in the delivery area, for a total range of 100 miles. (B. Bus) 120 miles of daily service.

Speed: (A. Mini Van) 55 mi/h to travel to the delivery area and SAE "B" cycle in the delivery area. (B. Bus) SAE "B" cycle. The cruise speed of the SAE "B" cycle is 20 mi/h.

Grades: Should handle 6% grade for 15% of the distance and 15% grade for 5% of the distance.

Top speed: (A. Mini Van) Maximum velocity of at least 60 mi/h for highway traffic. (B. Bus) Maximum velocity of at least 45 mi/h for traffic compatibility.

Acceleration: (A. Mini Van) 0 to 40 mi/h in 20 seconds. (B. Bus) 0 to 35 mi/h in 20 seconds.

Comments: One stop every 3 blocks. 7 hour driving scenario for the van and a 13 hour driving scenario for the bus.

(III) Parcel Post Delivery Van
(Long Range Delivery)

Range (two options): (A) 100 miles of delivery. (B) 50 miles to travel to the delivery area plus 100 miles of delivery, for a total range of 150 miles.

Speed: 55 mi/h to travel to the delivery area and SAE "C" cycle in the delivery area. The SAE "C" cycle has a cruise speed of 30 mi/h.

Grades: Should handle 6% grade for 20% of the distance.

Top speed: Maximum velocity of at least 60 mi/h for highway traffic.

Acceleration: 0 to 40 mi/h in 20 seconds.

Comments: 3 stops per mile. 7 and 8 hour driving scenarios respectively.

(IV) Urban Automobile
Home/Work Automobile
(City Scenario)

Range: 30 miles on highway and 30 miles in the city, for a total of 60 miles.

Speed: 55 mi/h on the highway and SAE "D" cycle in the city. The SAE "D" cycle has a cruise speed of 45 mi/h.

Grades: Should handle 6% grade for 15% of the distance and 15% grade for 5% of the distance.

Top speed: Maximum speed of at least 85 mi/h.

Acceleration: 0 to 50 mi/h in 20 seconds.

Comments: Approximately 1.5 hour driving scenario.

(V) Large Metropolitan Area Automobile
(Large City Automobile)

Range (two options): (A) 120 miles on highway plus 30 miles on the

city, for a total range of 150 miles. (B) 160 miles on highway plus 40 miles in the city, for a total range of 200 miles.
Speed: 60 mi/h on highway and SAE “D” cycle in the city.
Grades: Should handle 6% grade for 15% of the distance and 15% grade for 5% of the distance.
Ton speed: Maximum speed of at least 85 mi/h.
Acceleration: 0 to 50 mi/h in 20 seconds.
Comments: 3 hour and 4 hour driving scenarios respectively.

(VI) Intercity Automobile or Bus
Range: 480 miles of driving between cities.
Speed: 60 mi/h.
Grades: Should handle 6% grade for 15% of the distance.
Top speed: Maximum speed of at least 85 mi/h.
Acceleration: (A. Automobile) 0 to 50 mi/h in 20 seconds. (B. Bus) 0 to 45 mi/h in 20 seconds.
Comments: 8 hour driving scenario.

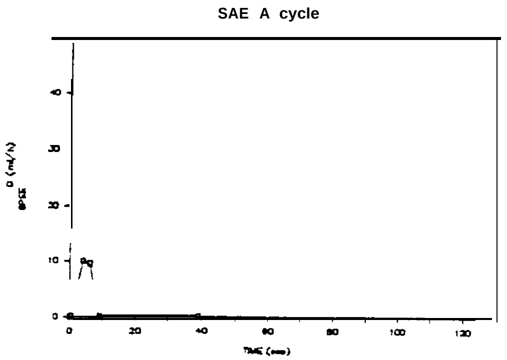
3.2 VEHICLE DESCRIPTIONS

A specific vehicle was selected for each driving scenario. The parameters that characterize each vehicle are summarized in Table 3. The mini van parameters were selected close to those of the TEvan and UNIQ Chrysler T115 mini vans. The parameters chosen to represent the full-size van are similar to those of the G-van. The automobile corresponds to a compact 5 person automobile.

TABLE la: DRIVING SCENARIOS GENERAL RANGE DESCRIPTION

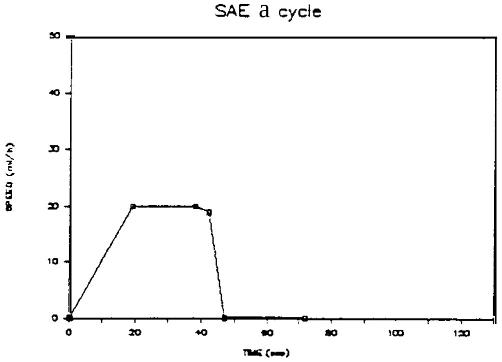
I. RESIDENTIAL POSTAL (13 mi)

10 mi at V=30 mi/h + 3 mi of



II.A. SMALL LOCAL DELIVERY SCENARIO (100 mi)

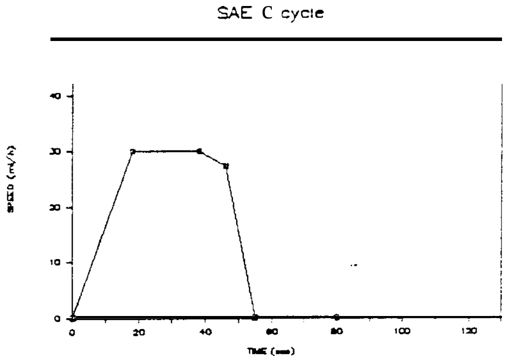
40 mi at V=55 mi/h + 60 mi of



III. LONG DELIVERY SCENARIO

A. (100 mi)

100 mi of



B. (150 mi)

50 mi at V=55 mi/h + 100 mi of

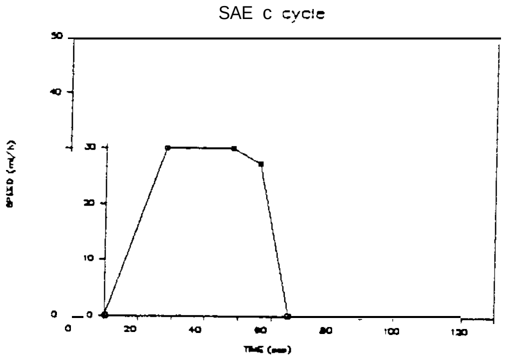
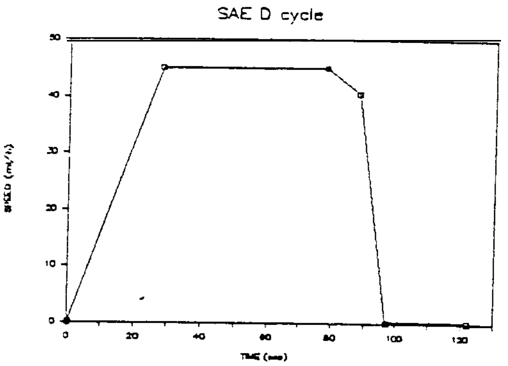


TABLE lb

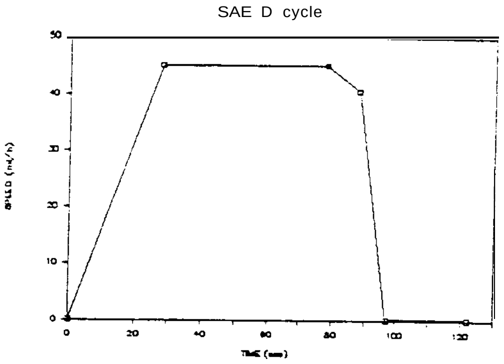
IV. **CITY SCENARIO (60 mi)**

30 mi at V=55 mi/h + 30 mi of



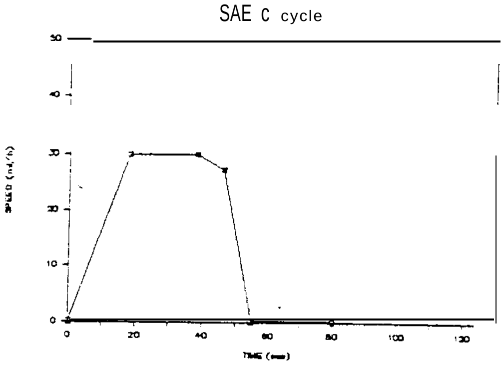
V. **LARGE METROPOLIS SCENARIO**
A. **(150** mi)

120 mi at V=60 mi/h + 30 mi of



B. (200 mi)

160 mi at V=60 mi/h + 40 mi of



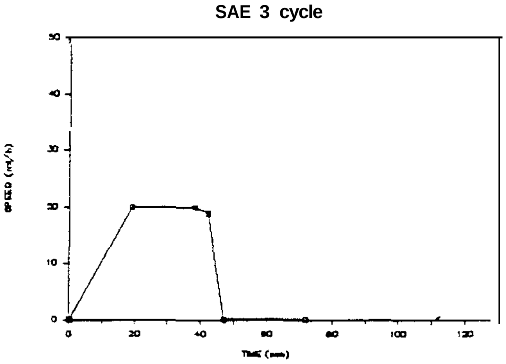
VI.A. **INTERCITY SCENARIO (480** mi)

480 mi at V=60 mi/h

TABLE lc

II.B. LOCAL BUS (120 ni)

120 mi of



VI.B. INTERCITY BUS (480 mi)

480 mi at V=60 mi/h

TABLE 2: DRIVING SCENARIOS

DRIVING SCENARIOS		SELECTED VEHICLE!	TOTAL DRIVING RANGE	DRIVING RANGE DESCRIPTION					ADDITIONAL REQUIR.	
				Distance at SAE **cycle**	Distance at constant Velocity	% dist. on 6% grade	% dist. on 15% grade	Driving The	Accel. in 20 sec	Top Speed (flat)
I.	Residential Postal	Mail Del. Vehicle	13 mi	3 mi (A)	10 mi (30mph)	50%	0%	3 hours	-- --	45 mph
II.A	Small Delivery	Mini Van	100 mi	60 mi (B)	40 mi (55mph)	15%	5%	7 hours	O-40 mph	60 mph
III.A	Long Delivery (A)	Van	100 mi	100 mi (C)	-- -- (-)	20%	0%	7 hours	O-40 mph	60 mph
III.B	Long Delivery (B)	Van	150 mi	100 mi (C)	50 mi (55mph)	20%	0%	8 hours	O-40 mph	60 mph
IV.	City Scenario	Automobile	60 mi	30 mi (D)	30 mi (55mph)	15%	5%	1.5 hours	O-50 mph	a5 mph
V.A	Large Metropolis (A)	Automobile	150 mi	30 mi (D)	120 mi (60mph)	15%	5%	3 hours	O-50 mph	a5 mph
V.B	Large Metropolis (8)	Automobile	200 mi	40 mi (D)	160 mi (60mph)	15%	5%	4 hours	O-50 mph	a5 mph
VI.A	Intercity	Automobile	480 mi	-- -- (-)	480 mi (60mph)	15%	0%	8 hours	O-50 mph	a5 mph
VI.B	Intercity	BUS	480 mi	-- -- (-)	480 mi (60mph)	15%	0%	8 hours	O-45 mph	a5 mph
II.B	Local BUS	BUS	120 mi	120 mi (8)	-- -- (-)	15%	5%	13 hours	O-35 mph	-- -

TABLE 3: VEHICLE CHARACTERISTICS

	MASS	FRONTAL AREA	DRAG COEF	ROLLING RESISTANCE COEF
MAIL DELIVERY VEHICLE	1400 Kg	2.5 m^2	0.45	0.01
	3090 lb	26.9 ft^2		
MINI VAN	2720 Kg	2.9 m^2	0.37	0.01
	6000 lb	31.2 ft^2		
FULL SIZE VAN	3400 Kg	3.4 m^2	0.47	0.01
	7500 lb	36.6 ft^2		
AUTOMOBILE	1400 Kg	1.9 m^2	0.30	0.01
	3090 lb	20.4 ft^2		
BUS	13600 Kg	8.9 m^2	0.50	0.01
	30000 lb	96.0 ft^2		

References for comparison:
G-Van GVW= 3528Kg, 77801b; A=3.485m^2, 37.5ft^2 ; Cd=0.463; Ur=O.Ol
Griffon GVW= 3072Kg, 6775113; A=3.35 m^2, 36.0ft^2 , Cd=0.47 ; Ur=0.0088

UNIQ Chrysler T115 GVW= 2729Kg, 60171b
TEVan GVW= 2675Kg, 59001b; A=2.92 m^2

4. ENERGY AND POWER REQUIREMENTS

4.1 DESCRIPTION OF THE ENERGY AND POWER SIMULATION PROGRAM FOR THE DRIVING SCENARIOS

Each driving scenario with its selected vehicle was analyzed using a simulation program to determine the propulsion force, power and energy needed to satisfy the driving scenario profile.

The inputs to the program were the vehicle parameters and the characteristics of the driving scenario under analysis. The simulation program analyzed each portion of the driving cycle (e.g. constant velocity portion, acceleration portion, etc.) to find out the force, power and energy needed to propel the vehicle.

The force needed for each portion of the driving scenario was based on the standard equations for aerodynamic drag, rolling resistance force, gravitational force component on a grade, and force needed to produce an acceleration (constant acceleration was assumed). A summary of the equations used is listed in Table 4.

Table 5 shows of a sample of the program output. Negative numbers under force, power or energy mean that the respective quantity had to be dissipated to follow the profile (e.g. during braking.) Regenerative braking efficiency refers to the percentage of this energy which would go back to the battery, while the rest would be dissipated by the brake pads or lost in inefficiencies of the regenerative braking system. Regenerative braking efficiency is an important parameter because it can substantially reduce the energy consumption for some driving scenarios.

In these initial analyses, air conditioning is not included. Also note, that the energy obtained is the energy to propel the vehicle, which is different from the energy at the battery terminals due to the transmission efficiency (controller, motor and transaxle).

4.2 DESCRIPTION OF THE POWER NEEDED TO MEET THE TOP SPEED POWER REQUIREMENT.

Given a velocity, the power needed to maintain that velocity can be calculated by using the equations in Table 6. Table 7 is a sample of the spreadsheet used to calculate the power required for a maximum top speed.

TABLE 4: SIMULATION PROGRAM EQUATIONS

FORCE= F(drag) + F(rol1) + F(grade) + F(acc)

F(drag) = (1/2)*Cd*ro*V^2*A . . . . ro=1.225 Kg/m^3

F(rol1) = Ur*W . . . . Ur=0.01

F(grade)= W*Sin(angle)

F(acc) = M(Vf-Vo)/t

POWER= FORCE * VELOCITY (instantaneous power)

ENERGY= FORCE * DISTANCE

ENERGY= (1/2)*Pmax*time (for constant acceleration)

TABLE 5: SIMULATION PROGRAM SAMPLE OUTPUT

```
TITLE:       (II) DRIVING SCENARIO, 5 PERSON CAR

Cd:                     0.3              r(Kg/m3):                1.225
Area(m2):               1.9              Gradel(%):                 6.0%
Ur:                    0.01              Grade2(%):                15.0%
Mass(Kg):              1400              Reg.Brake (n):            0.25


CONSTANT SPEED INFORMATION
Range:                   40 mi
%dist.grdl:            15.0%
Vconstant:               55 mi/h

CYCLE INFORMATION
Range:                   60 mi           CYCLE RESULTS
%di&t.grdl:            15.0%             V after (co):            18.94 mi/h
%dist.grd2:             5.0%
t(ac):                   19 s            dist/cycl(ac):           84.92 m
t(cr):                   19 s            dist/cycl(cr):          169.84 m
t(co):                    4 s            dist/cycl(co+br):        40.23 m
t(br):                    5 s            Total cycle dist:       294.98 m
Vcruise:                 20 mi/h         #cycles needed:         327.27

FORCES ANALYSIS
Fcn:                 348.17 N
 Fcn up/grl:        1169.89 N
 Fcn dw/grl:        -473.56 N
Fac:                 823.75 N
 Fac up/grl:        1645.47 N
 Fac dw/grl:           2.03 N
 Fac up/gr2:        2858.98 N
 Fac dw/gr2:       -1211.48 N
Fcr:                 165.10 N
 Fcr up/grl:         986.82 N
 Fcr dw/grl:        -656.63 N
 Fcr up/gr2:        2200.33 N
 Fcr dw/gr2:       -1870.13 N
Fco:                   0.00 N
 Fco up/grl:         821.72 N
 Fco dw/grl:        -821.72 N
 Fco up/gr2:        2035.23 N
 Fco dw/gr2:       -2035.23 N
Fbr:               -2208.58 N
 Fbr up/grl:       -1386.86 N
 Fbr dw/grl:       -3030.30 N
 Fbr up/gr2:        -173.35 N
 Fbr dw/gr2:       -4243.81 N
```

```
POWER  ANALYSIS
Pcn:                  8.56  KW
 Pen up/grl:         28.76  KW
 Pen dw/grl:        -11.64  KW
Pat:                  7.36  KW  -max-
 Pat up/grl:         14.71  KW  -max-
 Pat dw/grl:          0.02  KW  -max-
 Pat up/gr2:         25.56  KW  -max-
 Pat dw/gr2:        -10.83  KW  -max-
Per:                  1.48  KW
 Per up/grl:          8.82  IZW
 Per dw/grl:         -5.87  KW
 Per up/gr2:         19.67  KW
 Per dw/gr2:        -16.72  KW
Pco:                  0.00  Kw
 Pco up/grl:          7.35  Kw
 Pco dw/grl:         -7.35  Kw
 Pco up/gr2:         18.19  KW
 Pco dw/gr2:        -18.19  KW
Pbr:                -18.70  KW  -max-
 Pbr up/grl:        -11.74  KW  -max-
 Pbr dw/grl:        -25.66  KW  -max-
 Pbr up/gr2:         -1.47  KW  -max-
 Pbr dw/gr2:        -35.93  KW  -max-

ENERGY ANALYSIS

               Regen. n=l  Regen. n=25%   No Regen.

Ecn:                5.291        5.291            5.291      KWh
 Ecn up/grl:        1.569        1.569            1.569      KWh
 Ecn dw/grl:       -0.635       -0.159            0.000      KWh
Eac:                5.087        5.087            5.087      KWh
 Eac up/grl:        0. 95.3      0.953            0.953      KWh
 Eac dw/grl:        0.001        0.001            0.001      KWh
 Eac up/gr2:        0.552        0.552            0.552      KWh
 Eac dw/gr2:       -0.234       -0.058            0.000      KWh
Ecr:                2.039        2.039            2.039      KWh
 Ecr up/grl:        1.143        1.143            1.143      KWh
 Ecr dw/grl:       -0.760       -0.190            0.000      KWh
 Ecr upjgr2:        0.849        0 . 8 4 9        0.849      KWh
 Ecr dw/gr2:       -0.722       -0.180            0.000      KWh
Eco:                0.000        0.000            0.000      KWh
 Eco up/grl:        0.200        0.200            0.200      KWh
 Eco dw/grl:       -0.200       -0.050            0.000      KWh
 Eco upjgr2:        0.165        0.165            0.165      KWh
 Eco dw/gr2:       -0.165       -0.041            0.000      KWh
Ebr:               -3.400       -0.850            0.000      KWh
 Ebr up/grl:       -0.200       -0.050            0.000      KWh
 Ebr dw/grl:       -0.437       -0.109            0.000      KWh
 Ebr up/gr2:       -0.008       -0.002            0.000      KWh
 Ebr dw/gr2:       -0.204       -0.051            0.000      KWh

TOTAL  ENERGY      10.883       16.108           17.850      KWh
                    0.109        0.161            0.178    KWh/mi
```

TABLE 6: EQUATIONS FOR THE TOP SPEED POWER REQUIREMENT

POWER REQUIRED FOR A GIVEN TOP SPEED:

FORCE = F(drag) + F(rol1) . . . . Note: F(grade)=0, F(acc)=0;

F(drag) = (1/2)*Cd*ro*V^2*A

F(rol1) = Ur*W

POWER = FORCE * VELOCITY

TABLE 7: TOP SPEED POWER REQUIREMENT SAMPLE

```
TITLE:   MINI VAN

MASS(Kg):      2720
AREA(m2):       2.9
Ur:            0.01
Cd:            0.37

              TOP SPEED        POWER
                 (mi/h)         (KW)
              ----------  ----------
                   50.0      13.291
                   55.0      16.315
                   60.0      19.822
                   65.0      23.858
                   70.0      28.466
                   75.0      33.690
                   80.0      39.574
                   85.0      46.162
```

4.3 DESCRIPTION OF THE POWER NEEDED TO MEET THE ACCELERATION REQUIREMENT.

To determine the power needed to meet an acceleration requirement, say 0 to 50 mi/h in 20 seconds, velocity vs. time profiles for different vehicle power were obtained.

If the time is divided into small increments (dt), the approximations given in Table 8 can be used to reduce the degree of the polynomial that needs to be solved to second order. A sample of the velocity vs. time profiles for different vehicle power is given in Figure 1.

4.4 ENERGY RESULTS FOR ALL DRIVING SCENARIOS WITH THE SAME VEHICLE

The simulation program was run with the characteristics of the different driving scenarios. The same vehicle (the compact 5-person automobile) was initially used in all of the driving scenarios to determine how the energy requirements of the different scenarios compared to each other without considering the effects of different vehicle parameters such as mass, frontal area and drag coefficient.

The total energy and energy per mile needed are listed in Table 9 for different regenerative braking efficiencies. A regenerative braking efficiency of 0 means that none of the energy that needs to be dissipated goes back to the battery, while an efficiency of 1 represents the ideal case where all the energy goes back to the battery. Figure 2 is the histogram of the values listed in Table 9. One interesting point to note is that the energy per mile at 0% regenerative braking efficiency of the high speed scenarios, such as the intercity scenario, is about the same as that of the low speed scenarios, such as the small delivery scenario. In the high speed scenarios energy is consumed to overcome aerodynamic drag, while in the low speed scenarios energy is used to produce the frequent accelerations. Another interesting point is the fact that the low speed scenarios, with more stop-and-go driving, show more potential for energy consumption reductions due to regenerative braking than the high speed scenarios. The reason for this is that the low speed scenarios use most of the energy to meet the acceleration portions, but the acceleration portions are followed by braking periods where energy can be removed and sent to the battery. On the other hand, in the high speed scenarios the energy is simply lost in overcoming the aerodynamic drag.

The variations in the total energy required for the different scenarios are the result of the different driving ranges.

TABLE 8: EQUATIONS FOR THE ACCELERATION POWER REQUIREMENT

VELOCITY VS TIME PROFILES:

FORCE = F(drag) + F(rol1) + F(acc)

F(drag)= $(1/2)*Cd*ro*Vinst^2*A$ . . . . . . Vinst=(Vf+Vo)/2; Approx. Vinst=Vo;

F(roll)= Ur*W

F(acc) = M*Acc . . . . dt->0 Acc=(Vf-Vo)/dt

POWER = FORCE * Vinst . . . . Vinst=(Vf+Vo)/2

TABLE 9: ENERGY CONSUMPTION FOR DRIVING SCENARIOS, SAME VEHICLE

COMPACT 5 PERSON AUTOMOBILE

	TOTAL ENERGY (KWh)			ENERGY/MILE (KWh/mi)		
	n=O	n=l	n=0.25	n=O	n=l	n=0.25
I (13 mi)	2.729	1.125	2.328	0.210	0.087	0.179
II (100 mi)	17.850	10.883	16.108	0.178	0.109	0.161
III (100 mi)	20.364	9.668	17.690	0.204	0.097	0.177
III (150 mi)	29.203	17.448	26.264	0.195	0.116	0.175
IV (60 mi)	11.989	8.588	11.139	0.200	0.143	0.186
V (150 mi)	29.412	24.744	28.245	0.196	0.165	0.188
V (200 mi)	39.216	32.992	37.660	0.196	0.165	0.188
VI (480 mi)	90.271	83.296	88.527	0.188'	0.174	0.184

* Energy to propel the vehicle (does not include controller, motor and transaxle efficiency)

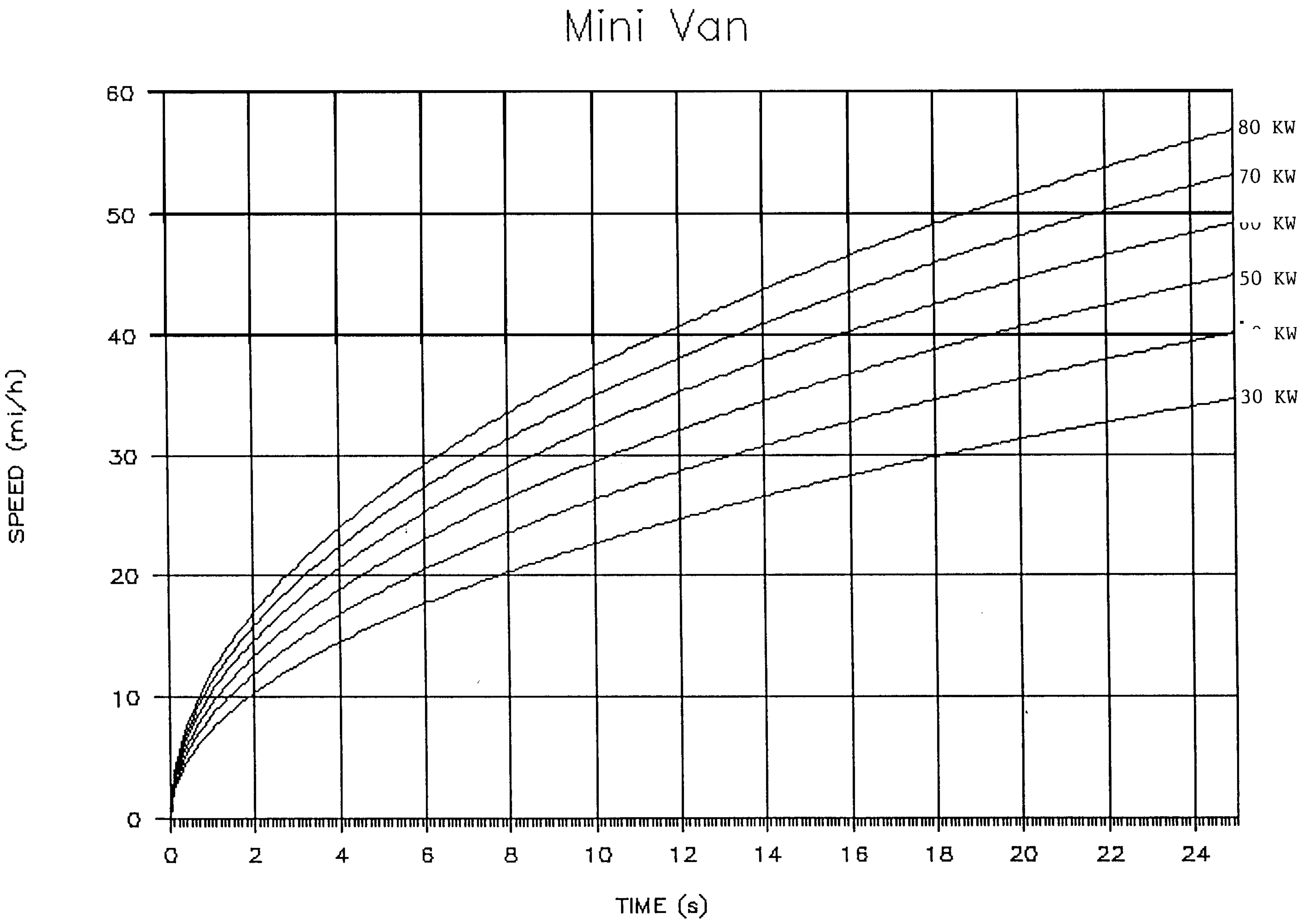
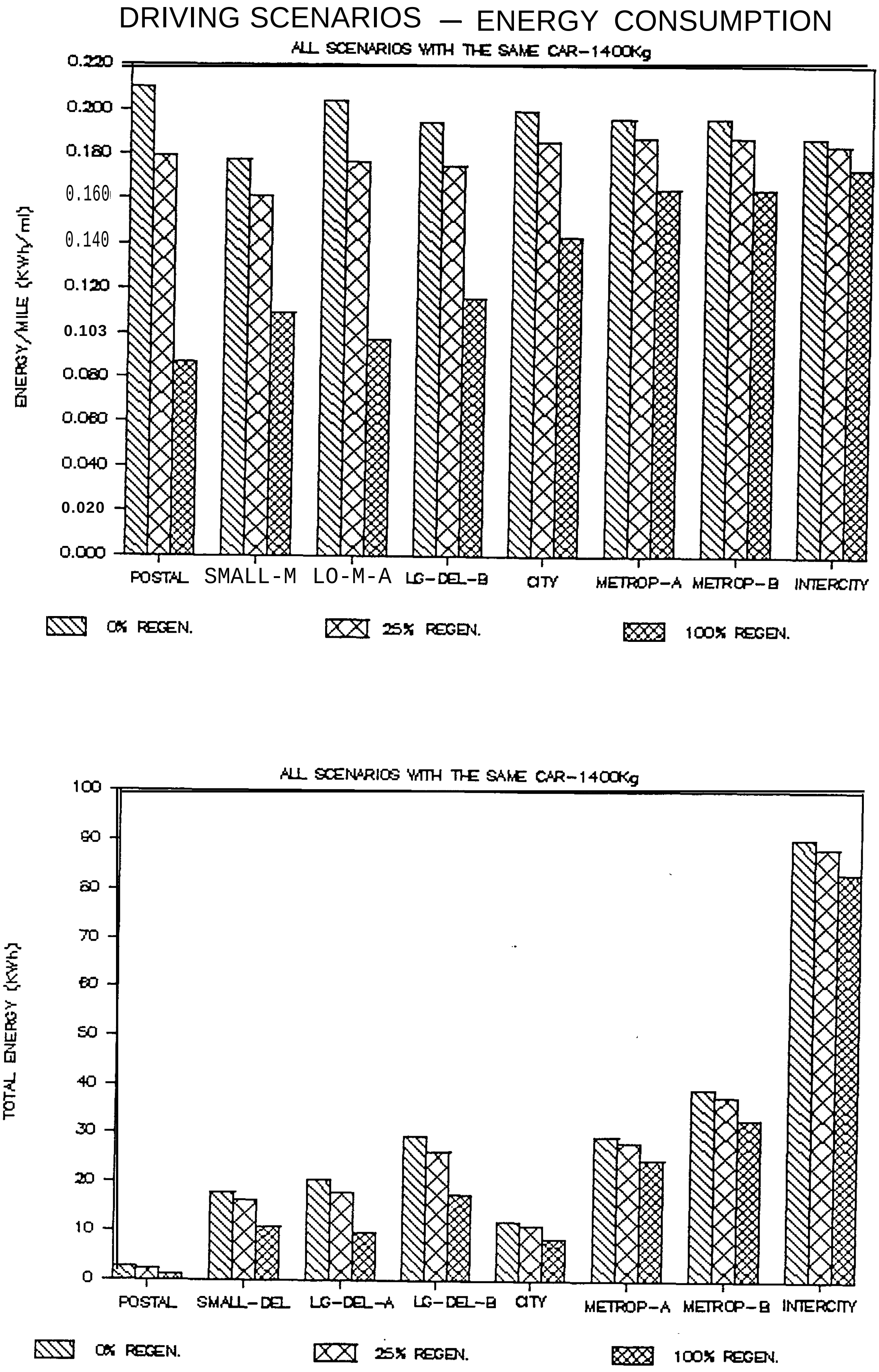


FIGURE 1: VELOCITY VS. TIME PROFILE SAMPLE

FIGURE 2: ENERGY CONSUMPTION FOR DRIVING SCENARIOS, SAME VEHICLE



The force, power and energy required for each portion of each of the driving scenarios with the same vehicle can be found in Appendix Al, where the simulation results are listed.

4.5 RESULTS FOR ALL DRIVING SCENARIOS WITH THEIR SELECTED VEHICLES

4.5.1 Energy requirements

This time, the simulation program was run with each driving scenario using its selected vehicle to calculate the energy required for the different designs. Table 10 lists the energy consumption for the different driving scenarios under different regenerative braking efficiencies. In Figure 3, it can be noticed that now the energy per mile for the different scenarios varies widely due to the different vehicle parameters. The potential for energy savings due to regenerative braking keeps its previous trend of being higher for low speed driving scenarios. Figure 4 shows the energy consumption for the driving scenarios that involve buses.

The results of the simulations for the driving scenarios with their selected vehicles are listed in Appendix A2.

A conservative assumed regenerative braking efficiency of 25% was used for the remainder of this study. This value produced a 10% reduction in the energy per mile needed by the mini van in the small delivery scenario, which compares satisfactorily with the 10 and 13% reductions found on track tests performed on the ETX-1 mini van on the FUDS cycle [4].

Recall that the energy shown in the figures is the energy needed to propel the vehicle. If the reader wishes to compare some of the results with actual road tests (where the energy at the battery terminals is usually listed) the values listed in Figures 2, 3 and 4 have to be divided by the transmission efficiency (controller, motor and transaxle). The value assumed in the design sections of this paper for the transmission efficiency was 70%, which agrees with [4] where the controller efficiency varied around 94%, the motor around 82% and the transaxle around 92% under different driving tests.

To check the accuracy of the simulation program and the validity of its assumptions, road tests performed on the ETV-1 [5] and G-Van [6] were simulated by the program, using the 25% regenerative efficiency and 70% transmission efficiency, producing results that

TABLE 10: ENERGY CONSUMPTION FOR DRIVING SCENARIOS, SELECTED VEHICLES

	TOTAL ENERGY (KWh)			ENERGY/MILE (KWh/mi)		
	n=0	n=l	n=0.25	n=0	n=l	n='0.25
I (13 mi) Mail Del.	2.938	1.408	2.556	0.226	0.108	0.197
II.A (100 mi) Mini Van	34.432	20.869	31.041	0.344	0.209	0.310
III.A (100 mi) Van	50.212	24.577	43.803	0.502	0.246	0.438
III.B (150 mi) Van	73.269	45.240	66.261	0.488	0.302	0.442
IV (60 mi) Automobile	11.989	8.588	11.139	0.200	0.143	0.186
V.A (150 mi) Automobile	29.412	24.744	28.245	0.196	0.165	0.188
V.B (200 mi) Automobile	39.216	32.992	37.660	0.196	0.165	0.188
VI.A (480 mi) Automobile	90.271	83.296	88.527	0.188	0.174	0.184

II.B (120 mi) Bus	211.377	87.596	180.432	1.761	0.730	1.504
VI.B (480 mi) Bus	782.908	707.848	764.052	1.631	1.474	1.592

Energy to propel the vehicle (does not include controller, motor and transaxle efficiency).

FIGURE 3: ENERGY CONSUMPTION FOR DRIVING SCENARIOS,
SELECTED VEHICLES

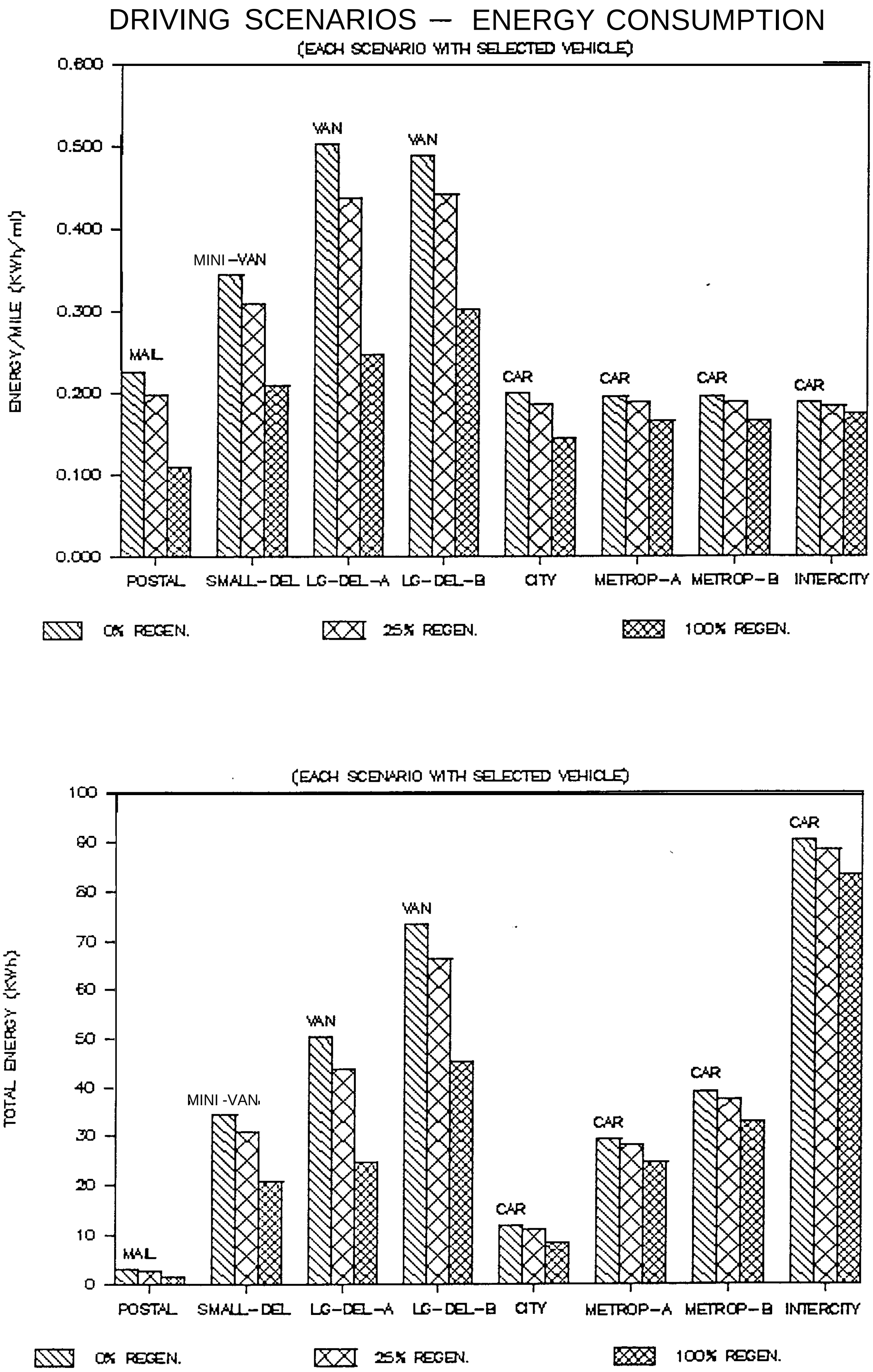
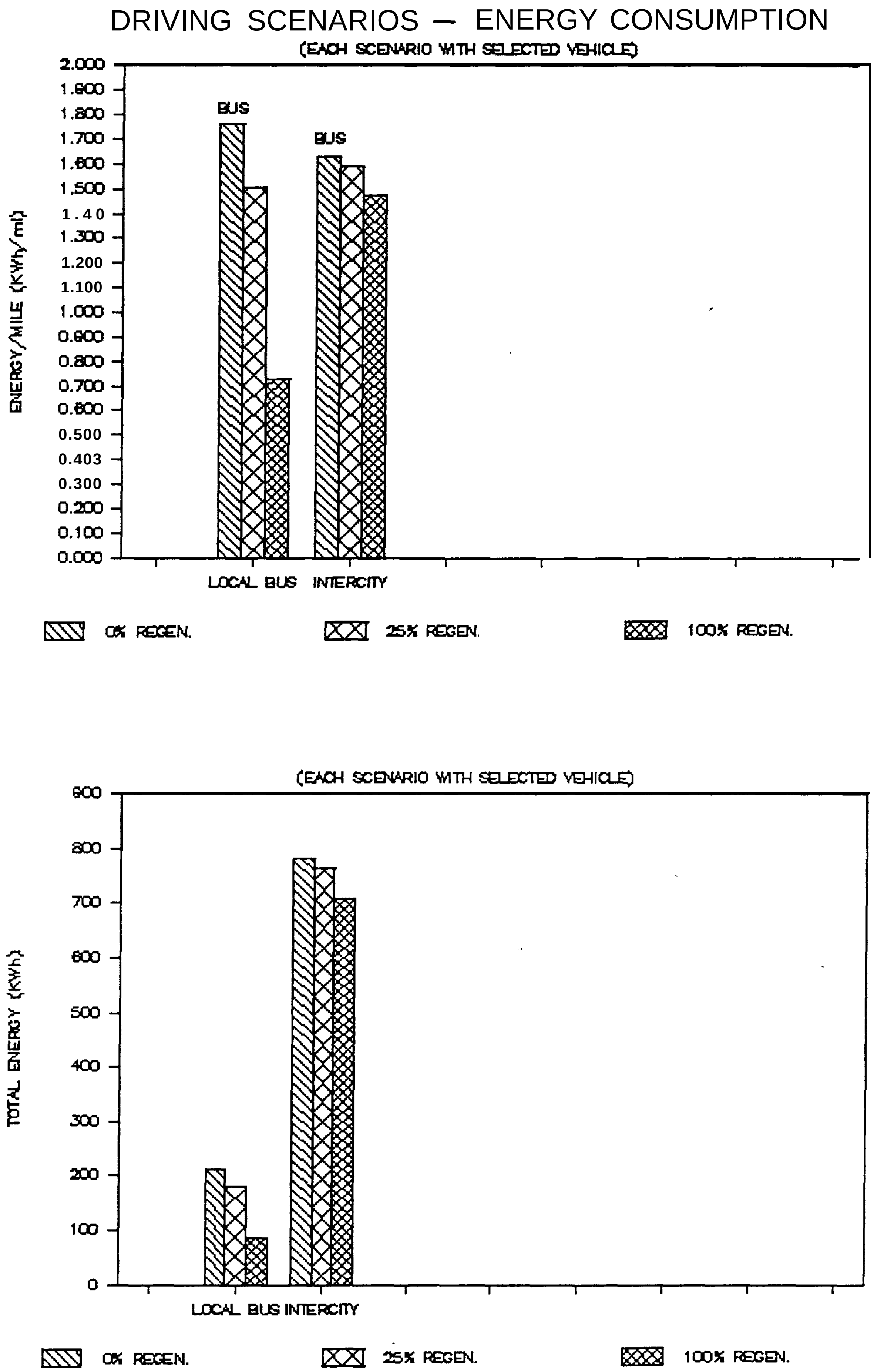


FIGURE 4: ENERGY CONSUMPTION FOR DRIVING SCENARIOS, BUSES



agreed to within 11% of the test results for these two vehicles under different driving conditions. The complete results can be found in Appendix A3.

4.5.2 Power Requirements

The power rating for the vehicle designs for each driving scenario was chosen to satisfy all <u>three</u> of the following: a) top speed requirement, b) acceleration requirement, and c) the driving scenario power requirement. Less significance was placed on the power that was needed to exactly follow the driving scenario profile over hills. It was recognized that the user should not expect such performance (e.g. accelerate to 45 mi/h in 20 seconds on a 15% hill).

The power selected for each vehicle and the limiting case are listed in Table 11.

The analysis done on each vehicle to find out the power needed to satisfy the top speed and acceleration requirements can be found in Appendix B.

Table 12 summarizes the total energy and peak power needed to propel the selected vehicles on their respective driving scenarios.

TABLE 11: POWER SELECTED FOR EACH VEHICLE

	POWER NEEDED	LIMITING CASE
MAIL DELIVERY VEHICLE	15 Kw	Driving scenario
MINI VAN	50 Kw*	Acceleration 0-40 mi/h in 20s
FULL SIZE VAN	60 KW*	Acceleration 0-40 mi/h in 20s
AUTOMOBILE	40 Kw	Acceleration 0-50 mi/h in 20s
LOCAL BUS	175 Kw	Acceleration 0-35 mi/h in 20s
INTERCITY BUS	300 Kw**	Acceleration 0-45 mi/h in 20s

* At this power, top speed on 6% grade would be 50 mi/h.

** At this power, top speed on 6% grade would be 55-60 mi/h

TABLE 12: SUMMARY OF ENERGY AND POWER REQUIREMENTS

SCENARIOS	TOTAL ENERGY (KWh)	PEAK POWER (KW)
RESIDENTIAL POSTAL, MAIL DELIVERY VEH. (13 mi)	2.56	15
SMALL DELIVERY, MINI VAN (100 mi)	31.04	50
LONG DELIVERY, FULL SIZE VAN (100 mi)	43.80	60
LONG DELIVERY, FULL SIZE VAN (150 mi)	66.26	60
CITY SCENARIO, AUTOMOBILE (60 mi)	11.14	40
LARGE METROPOLIS, AUTOMOBILE (150 mi)	28.25	40
LARGE METROPOLIS, AUTOMOBILE (200 mi)	37.66	40
INTERCITY, AUTOMOBILE (480 mi)	88.53	40
LOCAL BUS (120 mi)	180.43	175
INTERCITY, BUS (480 mi)	764.05	300

5. BATTERY AND RANGE EXTENDER

5.1 BATTERIES CONSIDERED

The batteries considered for the designs include: Na-S, Ni-Fe, Ni-Zn, Pb-Acid, and Pb-Acid gel cell. The characteristics of these batteries (or battery modules), as well as the references used, are listed in Table 13. Note that cost, life and reliability are still the biggest unknowns regarding these batteries, especially the most advanced ones, and are not explicitly addressed here.

5.2 RANGE EXTENDER

5.2.1 Engine-Generator

The report "Development and Demonstration of an Extended Range Electric Vehicle" by Chloride Limited EV Systems Division [3] included a figure summarizing a survey undertaken among manufacturers of engine-generator sets of the recreational vehicle type (e.g. for motor homes). This figure (reproduced as Figure 5 of this report) shows that for a given rated output power there are engine-generator sets that cover a wide range of weight. For the purpose of estimating the weight of the range extender, the engine-generators were clustered and the marked dots (see Figure 5) were used as the RX weight for the different output powers. For output powers in between the marked dots, linear interpolation was used.

For the one design that required a 100 KW RX (more details in the design section) the weight was estimated by adding the weight of an outboard marine engine and an electric generator for that given power.

5.2.2 Other energy sources

Other energy sources considered included fuel cells and solar energy Solar energy was discarded due to the large panels that would be required to obtain the power needed to propel the different vehicles. Fuel cells, such as the aluminum air, were discarded due to their low power density, the need for high performance electrodes and specially, the need for cost reduction [7] [8].

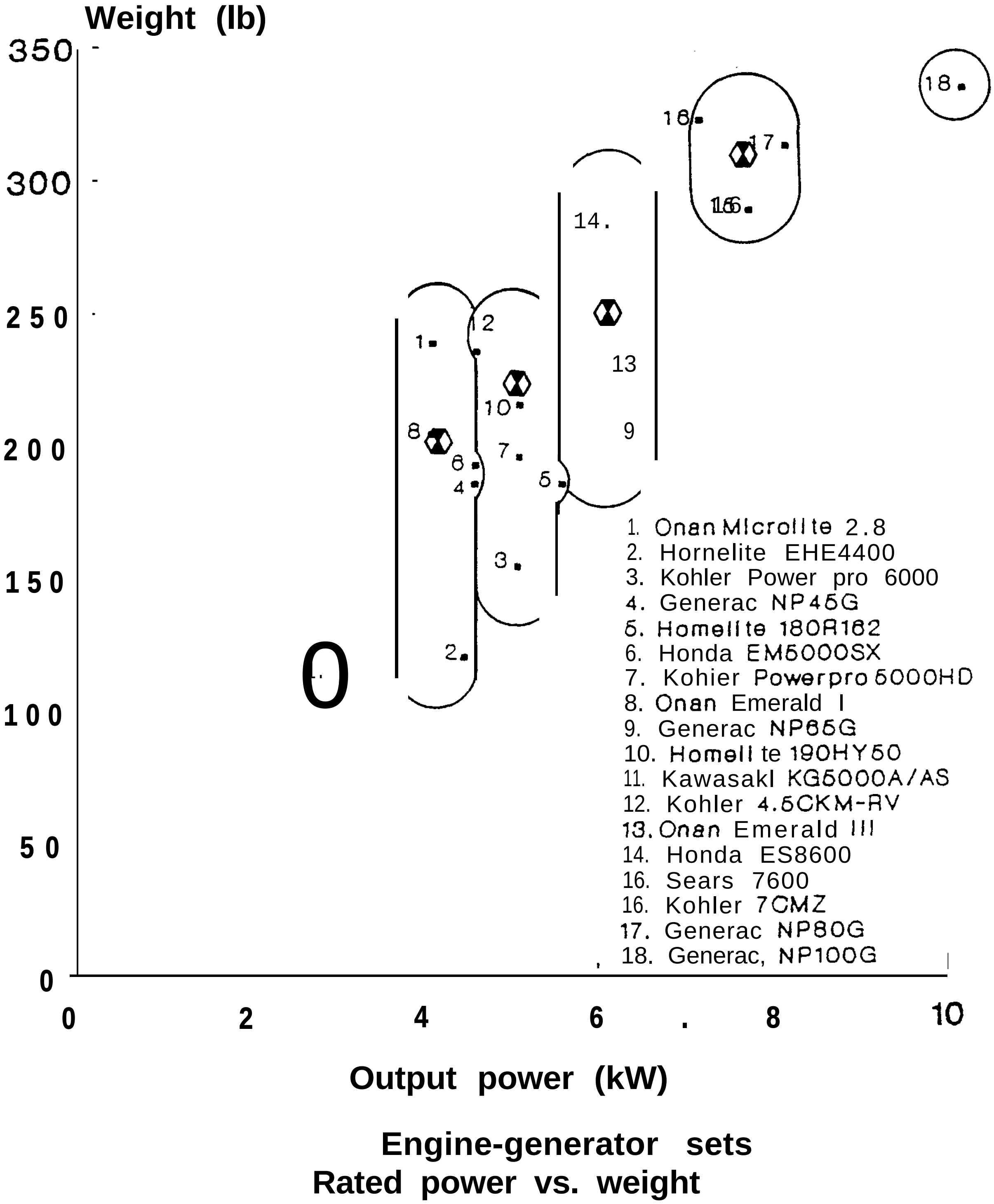
TABLE 13: BATTERY CHARACTERISTICS

		SPECIFIC POWER	SPECIFIC ENERGY	LIFE	Corn.	Ref.
Na-S	Chloride Silent Power Ltd	130 W/Kg	96 Wh/Kg	550 cycles	(1)	[16]
Ni-Fe NIF225	Eagle-Picher	110 W/Kg	53 Wh/Kg	500 cycles	(1)	[16]
Ni-Zn	Delco-Remy	120 W/Kg	52 Wh/Kg	600 cycles	(2)	[17]
Pb-Ac GC-6V-200	Johnson Controls Inc.	80 W/Kg	22 Wh/Kg	400 cycles	(1)	[16]
Pb-Ac EV-5T	Chloride	62 W/Kg	32 Wh/Kg	1200 cycles	(2)	[17]

References:
[16] 12th Annual Report to Congress for Fiscal Year 88, Electric Vehicle Program, February 1989.
[17] R.A. Renner and L.G. O'Connell. VIII International Electric Vehicle Symposium, "The Hybrid Vehicle Revisited", October 1986.

Comments:
(1) Specific Power @ 50%DOD; Cycles to 80%DOD; battery modules.
(2) Specific Power @ 80%DOD; Cycles to 80%DOD; batteries; Specific Energy @ 3h rate.

FIGURE 5: ENGINE GENERATOR SETS [3]



Reference:

Development and Demonstration of an Extended Range Electric Vehicle. Phase I Report. EPRI rp.2664-5. Chloride Limited EV Systems Division. J.E. Hammond. March 1989.

6. DEVELOPMENT OF PROPULSION SYSTEM DESIGNS

6.1 DESIGN CRITERIA

Electric and hybrid vehicle designs were developed based on the energy and power requirements obtained in Section 4.5 for the different driving scenarios with their selected vehicles.

All the batteries were tried on electric and hybrid vehicle versions.

The target battery weight for electric vehicles, or battery and RX weight for hybrid vehicles, was set to 25% of the gross vehicle weight. Vehicle designs over the target weight were considered unsatisfactory due to their large battery mass fraction. Note that for the compact automobile, a secondary battery (or battery plus RX) target weight was set at 33% of the vehicle weight because there have been successful automobile designs with that battery mass fraction (e.g. ETV-1 31%, Evcort 34% [9]).

6.2 BATTERY AND RANGE EXTENDER SIZING METHOD

From Section 4.5 the energy needed to operate the vehicles on the different driving scenarios is known. The total energy that the battery (or battery + RX) has to supply is larger than the energy to propel the vehicle due to the transmission efficiency (controller, motor and transaxle). As discussed earlier, the value assumed for the transmission efficiency is 70%. Therefore, the battery (or battery + RX) have to be designed for the propulsion energy divided by 70%.

The weight of battery required for an electric vehicle has to be the largest of the amount needed to satisfy the energy requirement (total energy divided by the specific energy going into 80% battery DOD) and the amount needed to satisfy the power requirement (power required divided by the specific power.)

Hybrid vehicles have to satisfy the same requirements of total energy and power. But now the total energy comes from the battery (battery mass times the specific energy going into 80% battery DOD) and from the range extender (range extender output power times the driving time.) The power required comes from the battery mass times the specific power and from the range extender output power. After observing the equations in Table 14, it can be noticed that the only unknowns are the battery mass (M) and the range extender power (RX POWER). By solving the two equations simultaneously for each considered battery technology, the optimal design can be obtained (optimal in the sense that the given battery mass and RX

TABLE 14: EQUATIONS FOR THE BATTERY AND RANGE EXTENDER SIZING METHOD

TOTAL ENERGY = ENERGY / TRANS.EFFICIENCY

ELECTRIC VEHICLES:

BATTERY WEIGHT1= TOTAL ENERGY / (80% SPECIFIC ENERGY)

BATTERY WEIGHT2 POWER REQUIRED / SPECIFIC POWER

HYBRID VEHICLES:

(RX POWER)*T + M*(80% SPECIFIC ENERGY) = TOTAL ENERGY

(RX POWER) + M*(SPECIFIC POWER) = POWER REQUIRED

RX POWER= unknown range extender power (KW)
M = unknown battery mass (kg)
T = driving time (h)
SPECIFIC ENERGY = (KWh/Kg)
SPECIFIC POWER = (KW/Kg)
TOTAL ENERGY = (KWh)
POWER REQUIRED = (Kw)

will match the total energy and power requirements exactly, without any extra energy or power). Round-off errors, especially when specifying RX power in convenient increments, mean that in fact both energy and power requirements are not met exactly, but one of the two is typically exceeded.

Table 15 shows a sample of the spreadsheet that was used to find: a)the battery mass needed for the electric vehicle designs, b)the battery mass and range extender output power for hybrid vehicle designs. Note that all designs were planned to only go to 80% battery DOD so that battery life would not be reduced. This can be seen in Table 15, by taking 80% of the energy listed to the right of each EV design to obtain the total energy required as listed at the top of the table. Similarly, for hybrid vehicles, the total energy required will be obtained by adding the total contribution from the RX and 80% of the battery energy.

6.3 VEHICLE DESIGNS WITHOUT AIR CONDITIONING

Figures 6 to 15 will be used to describe the most appropriate designs for each driving scenario with its selected vehicle. All the exact values for each of the designs can be found in Appendix C.

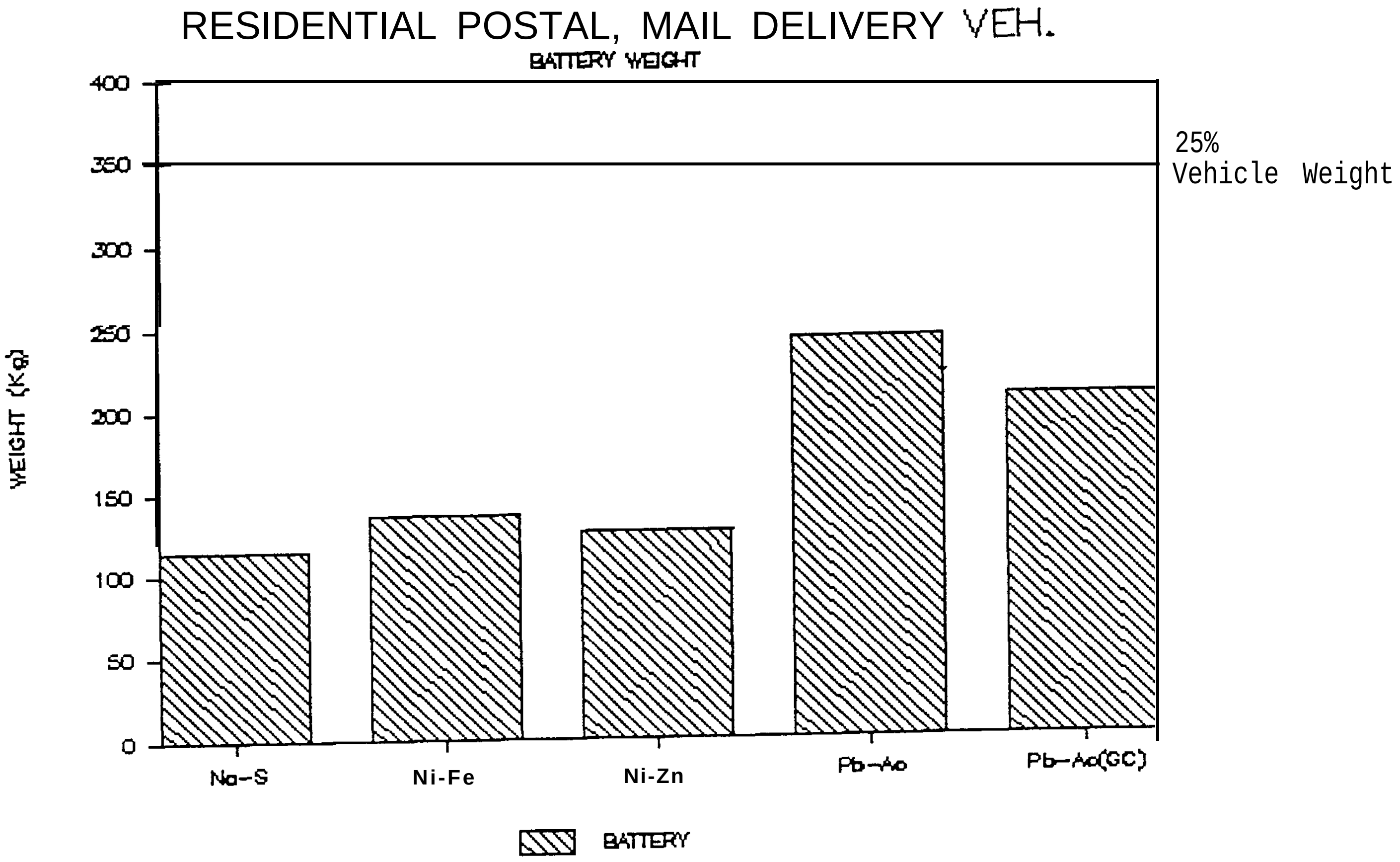
The designs for the residential postal driving scenario, with the mail delivery vehicle (Figure 6), show that electric vehicles are the best options. The reason for this is that all the batteries had to be sized to meet the power requirement. At that battery mass, more energy was available than needed for this scenario. Adding a range extender would only produce more energy that was not needed (since a RX can be visualized as a source of large amounts of energy, but small amounts of power). The fact that the battery of the electric vehicle contains extra energy is not necessarily bad. It means that the driving scenario could be completed with less than 80%DOD, therefore increasing battery life. Notice that all the battery technologies can meet the driving scenario requirements. The final decision on which to implement would be based on cost and life of the battery.

The mini van designs for the small delivery scenario are summarized in Figure 7. The designs whose battery weight (or battery + RX weight) is over the target weight are only shown for reference. For this scenario, the only electric vehicle feasible is the one using the Na-S battery. On the other hand, hybrid vehicles can be implemented using four of -the battery technologies analyzed. The required RXs range from 2.5 KW to 5 KW (the specific value for each design can be found in Appendix C). It is important to notice how a large amount of the energy needed can be obtained out of the small weight contribution of the RX. Also, if we consider Ni-Fe or Ni-

TABLE 15: BATTERY AND RANGE EXTENDER SIZING SAMPLE

```
DESIGNS: SMALL DELIVERY, MINI VAN
100 mi

Energy?            31.04     (@ n=0.25)
Transm.Eff?         0.70
Total Energy=      44.34 KWh

Power?              50.0 Kw

Driving time?       7.27 h
Veh.Weight?         2720 Kg
Veh.Weight/4  =      680 Kg (Target Weight)

EV:
Designed for 80% DOD of the battery.

Na-S  (CSPL)                     577 Kg      55.4 KWh     75.1 KW
Ni-Fe (NIF225)                  1046 Kg      55.4 KWh    115.0 KW
Ni-Zn (Delco-Remy)              1066 Kg      55.4 KWh    127.9 KW
Pb-Ac (EV-5T)                   1732 Kg      55.4 KWh    107.4 KW
Pb-Ac (GC-6V-200)               2519 Kg      55.4 KWh    201.6 KW

HV:
Designed for 80% DOD of the battery.

Na-S  (CSPL)                     365 Kg      35.1 KWh     47.5 Kw
rx                                54 Kg      18.2 KWh      2.5 KW
                            -------------------------------------
                                 419 Kg      53.3 KWh     50.0 Kw


Ni-Fe (NIF225)                   418   Kg   22.2   KWh  46.0   KW
rx                                90   Kg   29.1   KWh   4.0   Kw
                            ------------------------------------
                                 508   Kg   51.2   KWh  50.0   Kw


Ni-Zn (Delco-Remy)               383 Kg      19.9 KWh     46.0 KW
rx                                90Kg       29.1 KWh      4.0 Kw
                            -------------------------------------
                                 473 Kg      49.0 KWh     50.0 Kw


Pb-Ac (EV-5T)                    750 Kg      24.0 KWh     46.5 KW
rx                                74 Kg      25.4 KWh      3.5 Kw
                            -------------------------------------
                                 824 Kg      49.4 KWh     50.0 Kw


Pb-Ac (GC-6V-200)                563 Kg      12.4 KWh     45.0 Kw
rx                               102 Kg      36.4 KWh      5.0 Kw
                            -------------------------------------
                                 665 Kg      48.7 KWh     50.0 Kw
```

FIGURE 6: RESIDENTIAL POSTAL VEHICLE DESIGNS



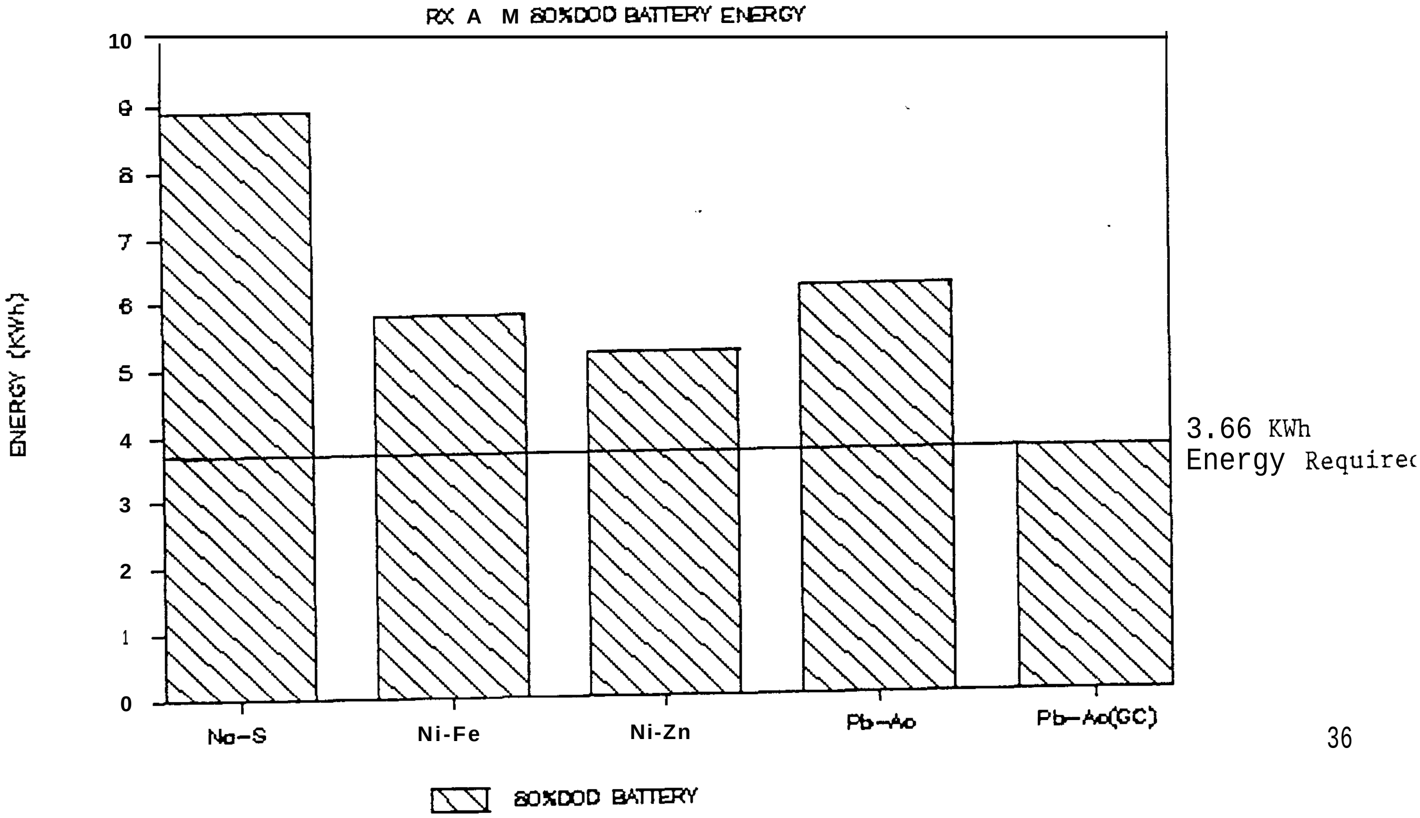
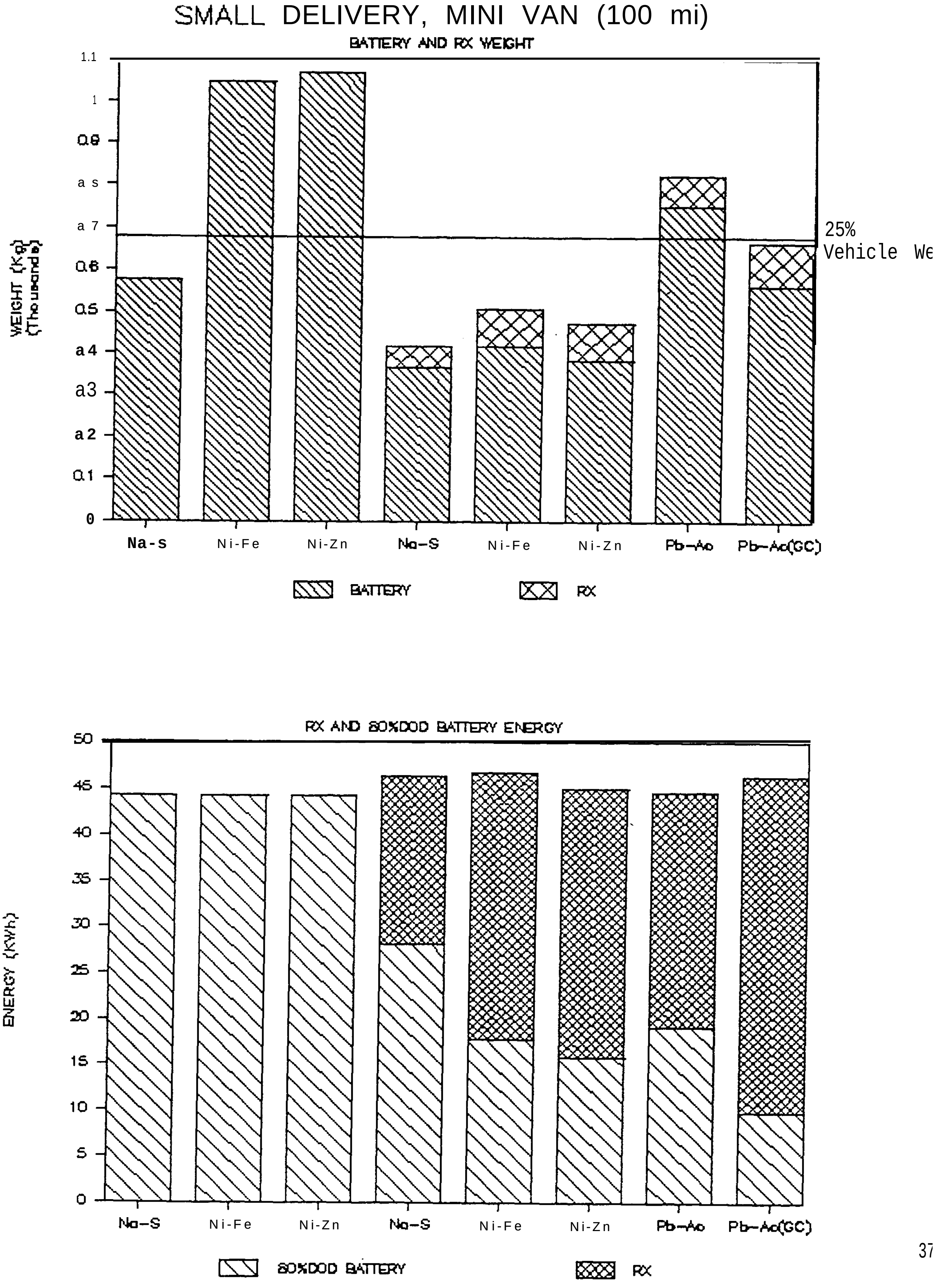


FIGURE 7: MINI VAN DESIGNS FOR THE SMALL DELIVERY SCENARIO



Zn, designs that were impossible as pure electric vehicles are now possible with a reduction of approximately 50% of the battery mass needed.

The van designs for the two long delivery driving scenarios (100 and 150 miles) are shown in Figures 8 and 9 respectively. The results are similar to those for the mini van. For the 100 mile scenario, there is only one electric vehicle design possible (Na-S), while there are several possible hybrid vehicles (Na-S, Ni-Fe, Ni-Zn and Pb-Ac gel cell). The sizes of the required RX range from 4.5 KW for the Na-S to 7.5 KW for the Pb-Ac gel cell. Comparing the Na-S as EV and as HV it can be seen that the 4.5 KW range extender can reduce the amount of battery needed by 375 Kg. The final decision on which to implement would be based on cost, and on how much importance is attached to pure battery operation.

For the 150 mile long delivery scenario, the vans would have to be hybrids using RXs from 8 to 10.5 KW. The 50 mile range increase, with respect to the previous 100 mile range, eliminated the Na-S as EV. Note how more than 50% battery weight can be saved by adding an 8 KW range extender to the Na-S design. But it is not essential to use Na-S for the hybrid, since the designs based on Ni-Fe and Ni-Zn would also be excellent solutions. To get an idea of how much battery weight can be replaced by the RX, the Ni-Fe as EV (not shown in Figure 9) would need 2200 Kg or pure battery (making it clearly infeasible), but as HV would only need 460 Kg-

The automobile designs for the city scenario (Figure 10) show that electric vehicles are the best option. The only batteries that would be able to meet the requirements are Na-S, Ni-Fe and Ni-Zn. The battery of the Na-S electric vehicle had to be sized to meet the power requirement and produced extra energy. The battery of the Ni-Fe electric vehicle matched both the energy and power requirement exactly. A Na-S or Ni-Fe hybrid vehicle would not reduce the battery weight needed because the range extender would only produce more unneeded energy. The Ni-Zn electric vehicle, on the other hand, had to be sized to meet the energy requirement. A hybrid vehicle is therefore an option for this scenario, but its benefits are minimal or none considering the additional level of complexity versus the minimal weight reduction.

The automobile designs for the large metropolis scenario (150 miles) are shown in Figure 11. Now that the range has increased, with respect to the previous scenario, only three hybrid vehicles can meet the requirements. Note that this increase in range makes RXs (7 to 9.5 KW) extremely useful, by looking at the weight reduction of the HVs based on Ni-Fe and Ni-Zn against their EV counterparts (which are clearly infeasible).

FIGURE 8: VAN DESIGNS FOR THE LONG DELIVERY SCENARIO (100 miles)

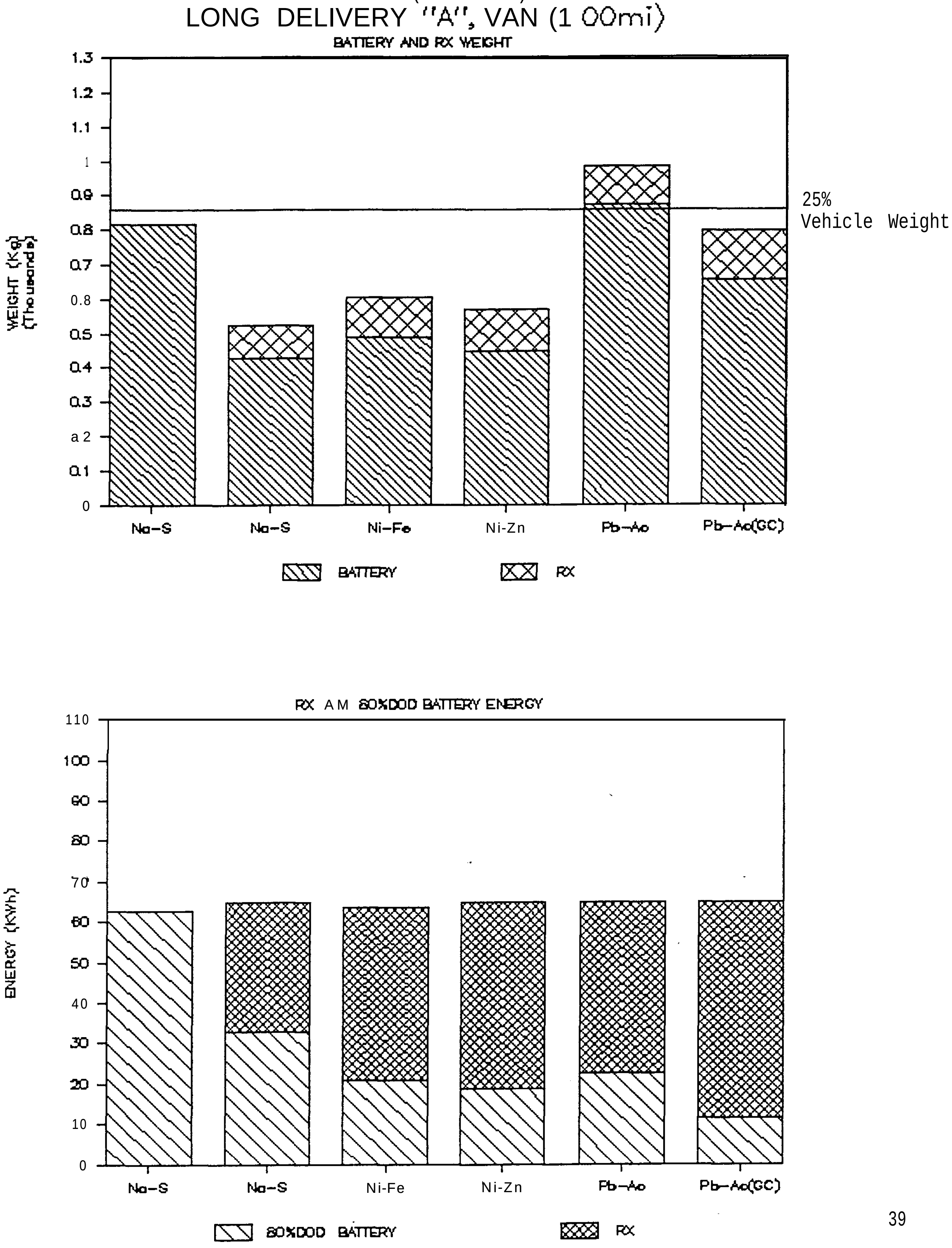
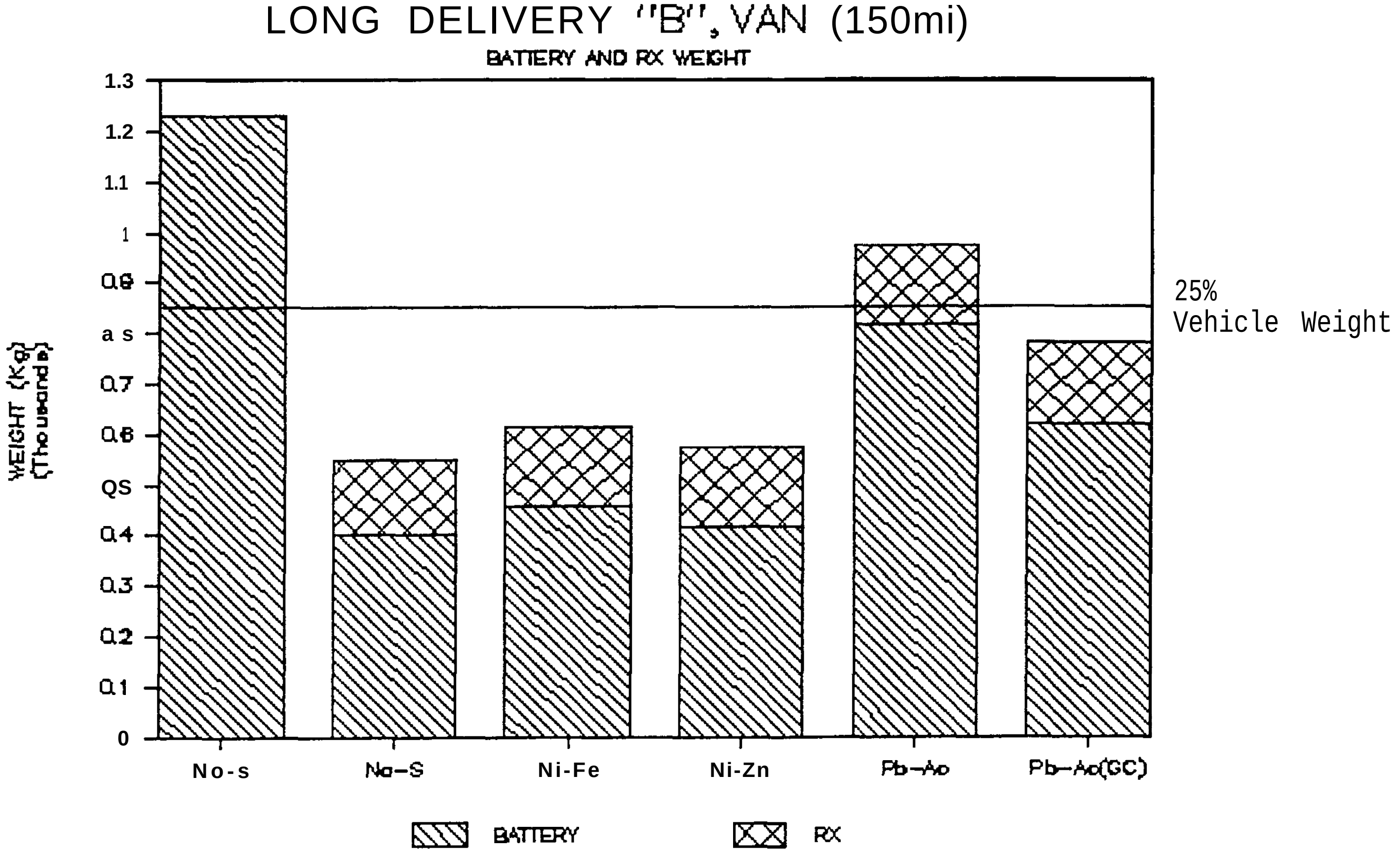


FIGURE 9: VAN DESIGNS FOR THE LONG DELIVERY SCENARIO (150 miles)



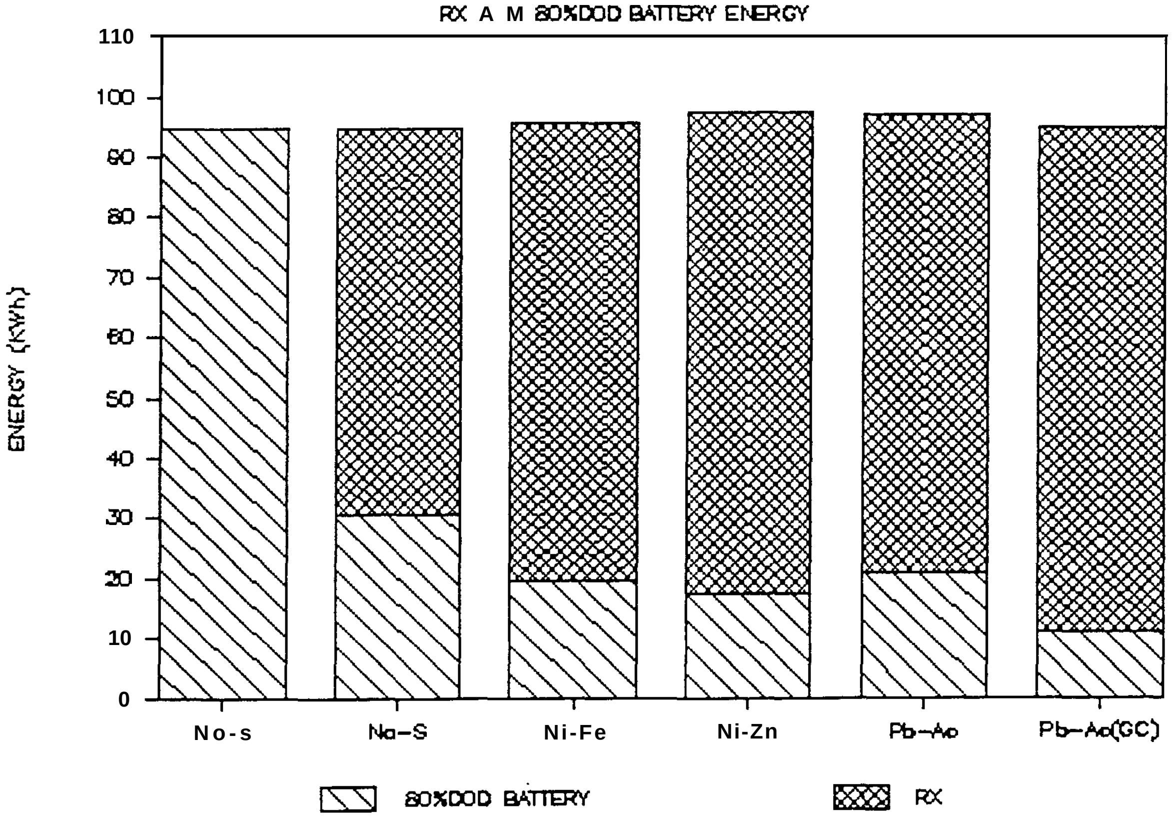


FIGURE 10: AUTOMOBILE DESIGNS FOR THE CITY SCENARIO

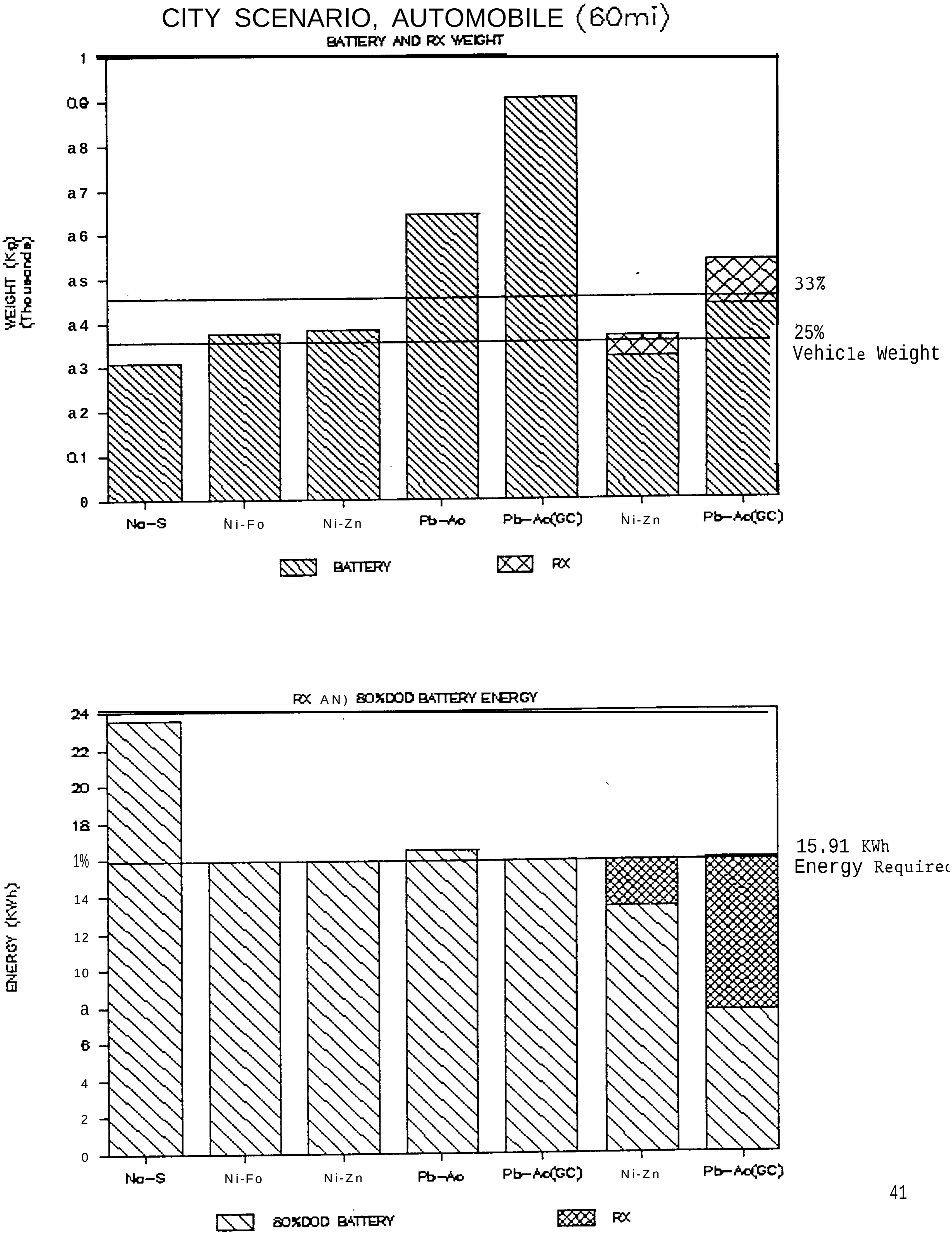
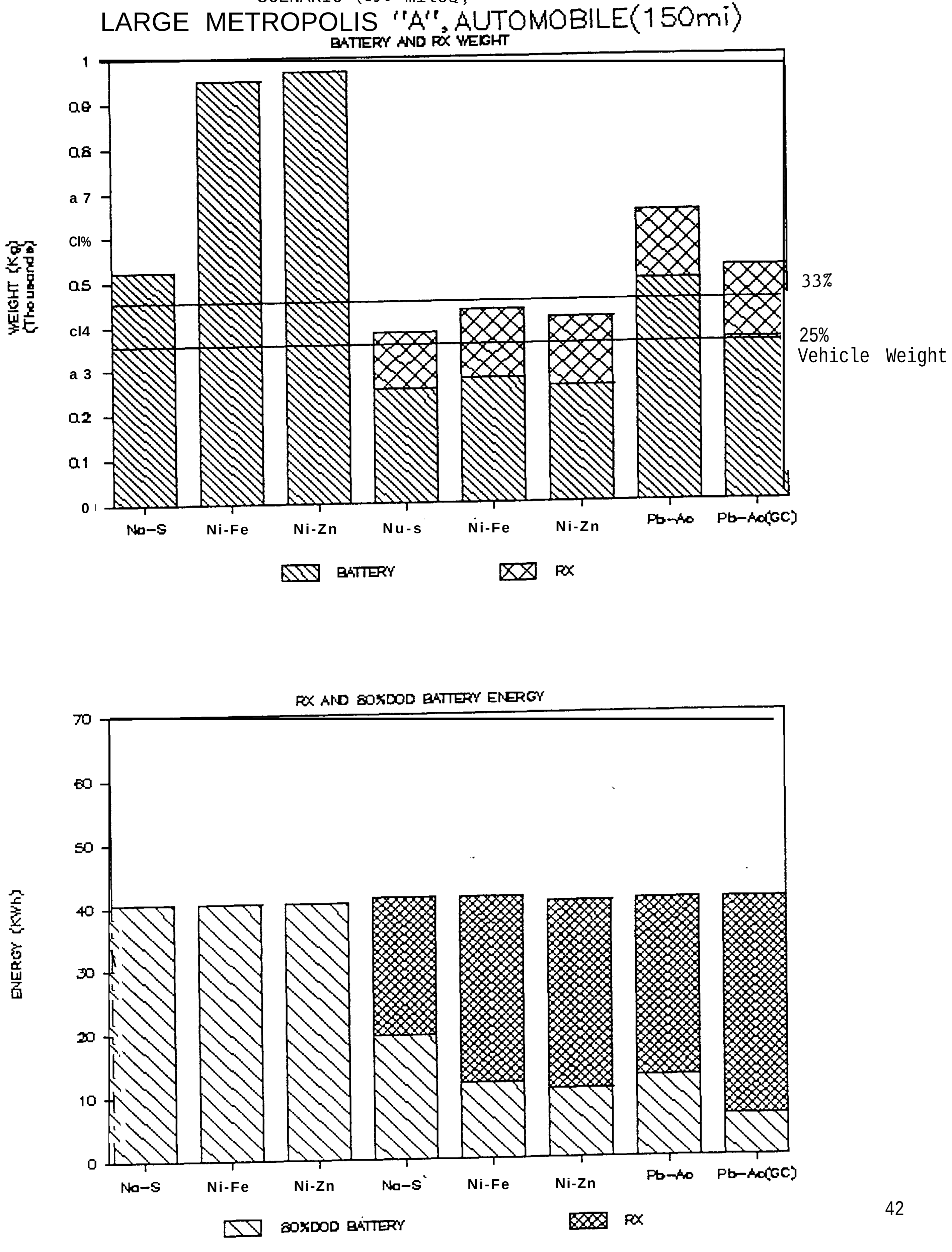


FIGURE 11: AUTOMOBILE DESIGNS FOR THE LARGE METROPOLIS SCENARIO (150 miles)



The 200 mile large metropolis scenario (Figure 12), can only be met by the same hybrid vehicles. The RXs used range from 8.5 to 10.5 KW.

The automobile designs for the intercity driving scenario are shown in Figure 13. This type of application could change the “limited range” idea that people have about battery powered vehicles. As expected, hybrid designs are needed. The RXs would range from 14 to 15 KW. It is impressive to see how much energy comes out of the range extender, more than 90% of the total energy needed. Even though the maximum range would be 480 miles, on most days the user would not drive for that distance. For days of 40 miles or less of driving, the hybrid vehicles could still offer pure battery operation.

The local bus scenario is an optimal application for hybrid vehicles. Figure 14 shows how a small RX (12.5 to 17 KW for this 175 KW bus) can reduce the amount of battery needed by thousands of kilograms. What makes this an optimal application is the large driving time involved. Long driving time scenarios allow the RX to produce large amounts of energy, as shown in Figure 14. All the battery technologies analyzed could meet the requirements well below the target weight (25% of the gross vehicle weight.)

The bus designs shown in Figure 15 for intercity scenario (480 miles travel), have to be hybrids but are questionable applications. What makes them questionable is the large RXs that would be needed. 130 KW (175 hp) for a 300 KW bus. Nevertheless, cleaner and more energy efficient operation could probably be obtained out of the hybrid buses than their diesel counterparts.

6.4 SENSITIVITY OF THE DESIGNS TO CHANGES IN BATTERY CHARACTERISTICS

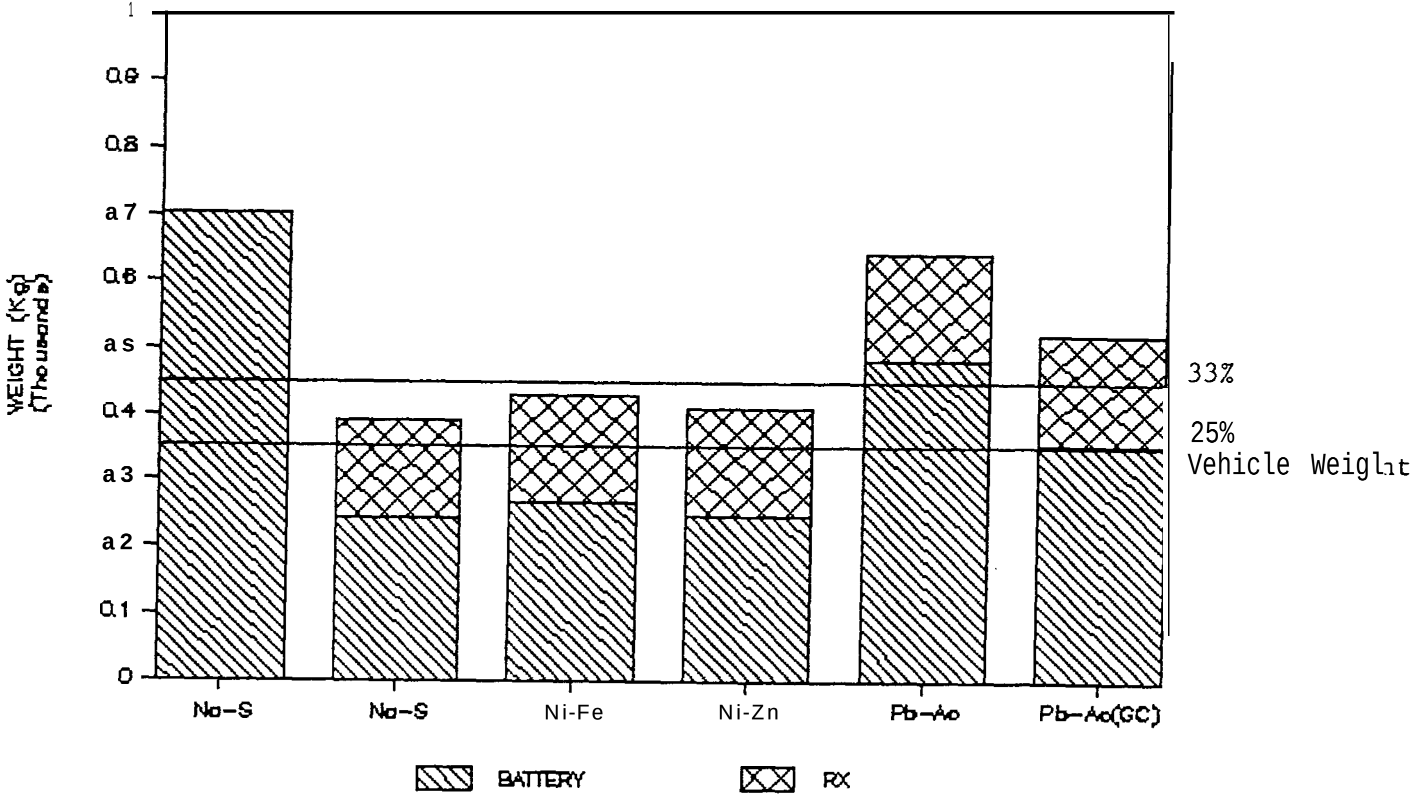
To determine the extent to which an inferior battery performance or an improvement in battery technology would affect the different designs, a sensitivity analysis was performed by changing the specific energy and specific power of each of the batteries listed on Table 13 by certain percentages. The changes considered were -20% and -30% for inferior performance and +20% and +30% for battery improvement.

An important point to notice (Figures 16-25) is that the RX output power required is weakly influenced by battery performance changes. In fact, if the specific power and specific energy are changed by the same percentage (as was done here), the RX output power required is exactly the same, independently of the percentage change. On the other hand, the

FIGURE 12: AUTOMOBILE DESIGNS FOR THE LARGE METROPOLIS SCENARIO (200 miles)

LARGE METROPOLIS "B", AUTOMOBILE(200mi)

BATTERY AND RX WEIGHT



RX ANY 80%DOD BATTERY ENERGY

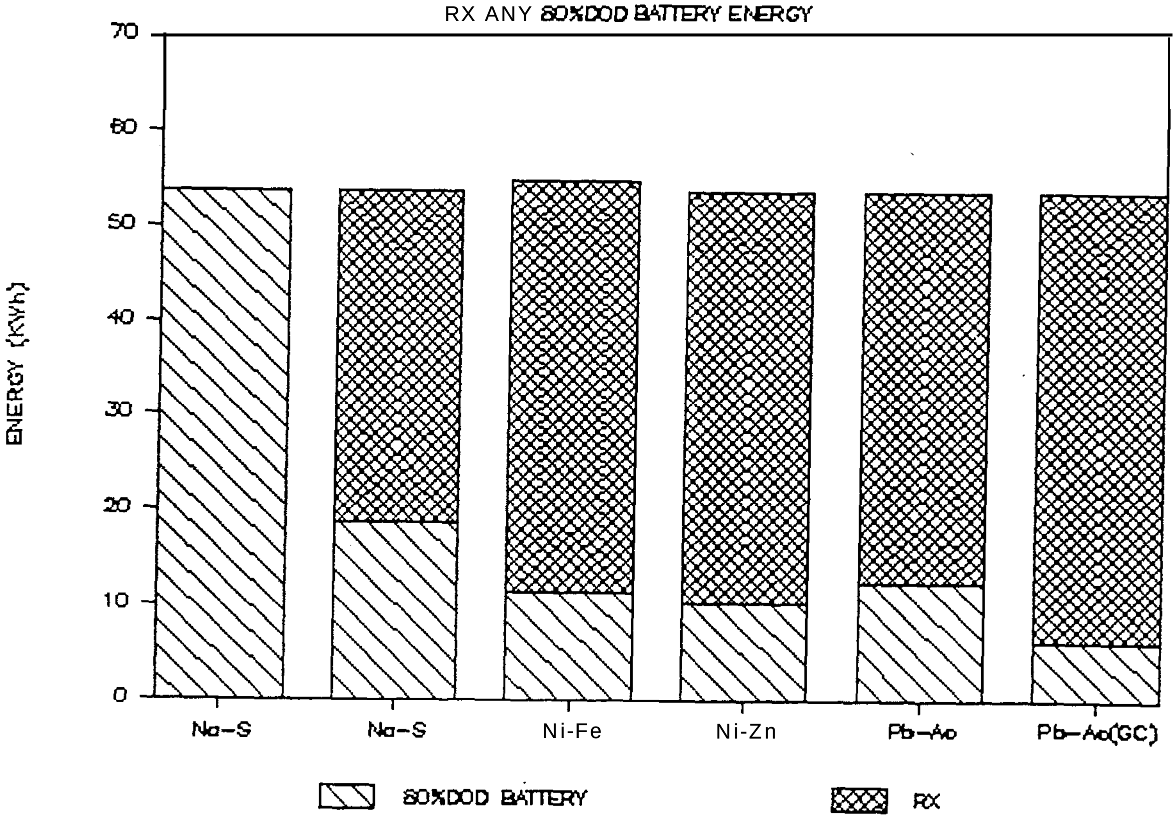
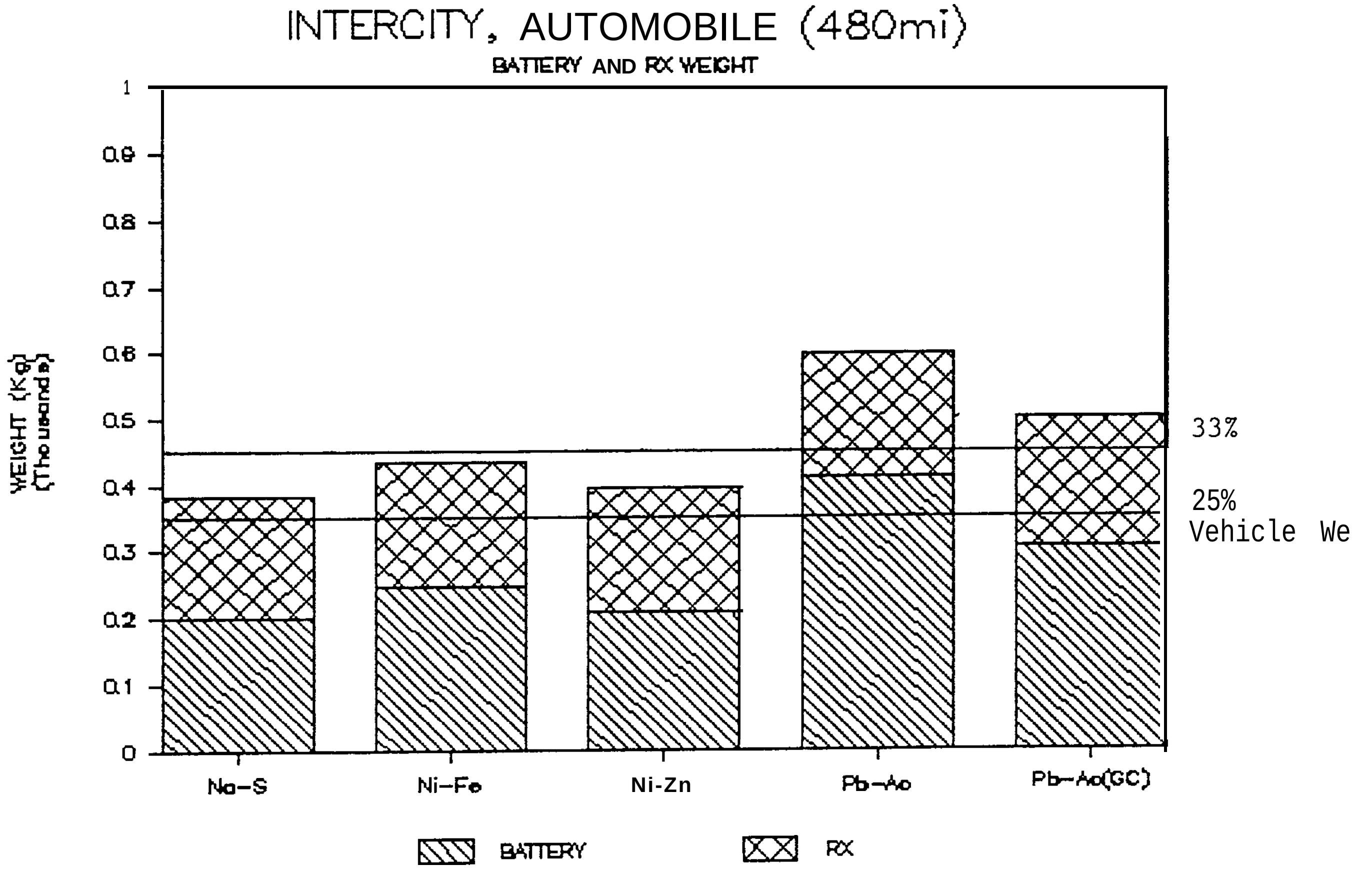


FIGURE 13: AUTOMOBILE DESIGNS FOR THE INTERCITY SCENARIO



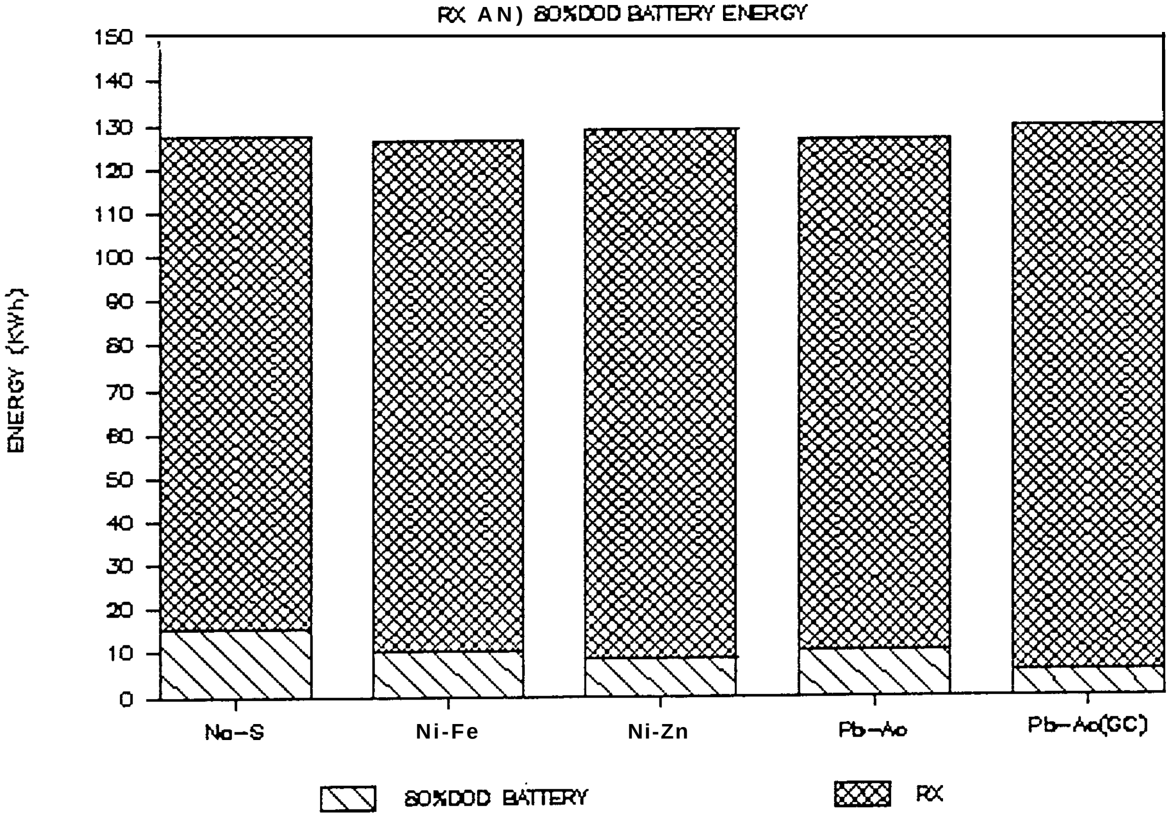


FIGURE 14: BUS DESIGNS FOR THE LOCAL BUS SCENARIO

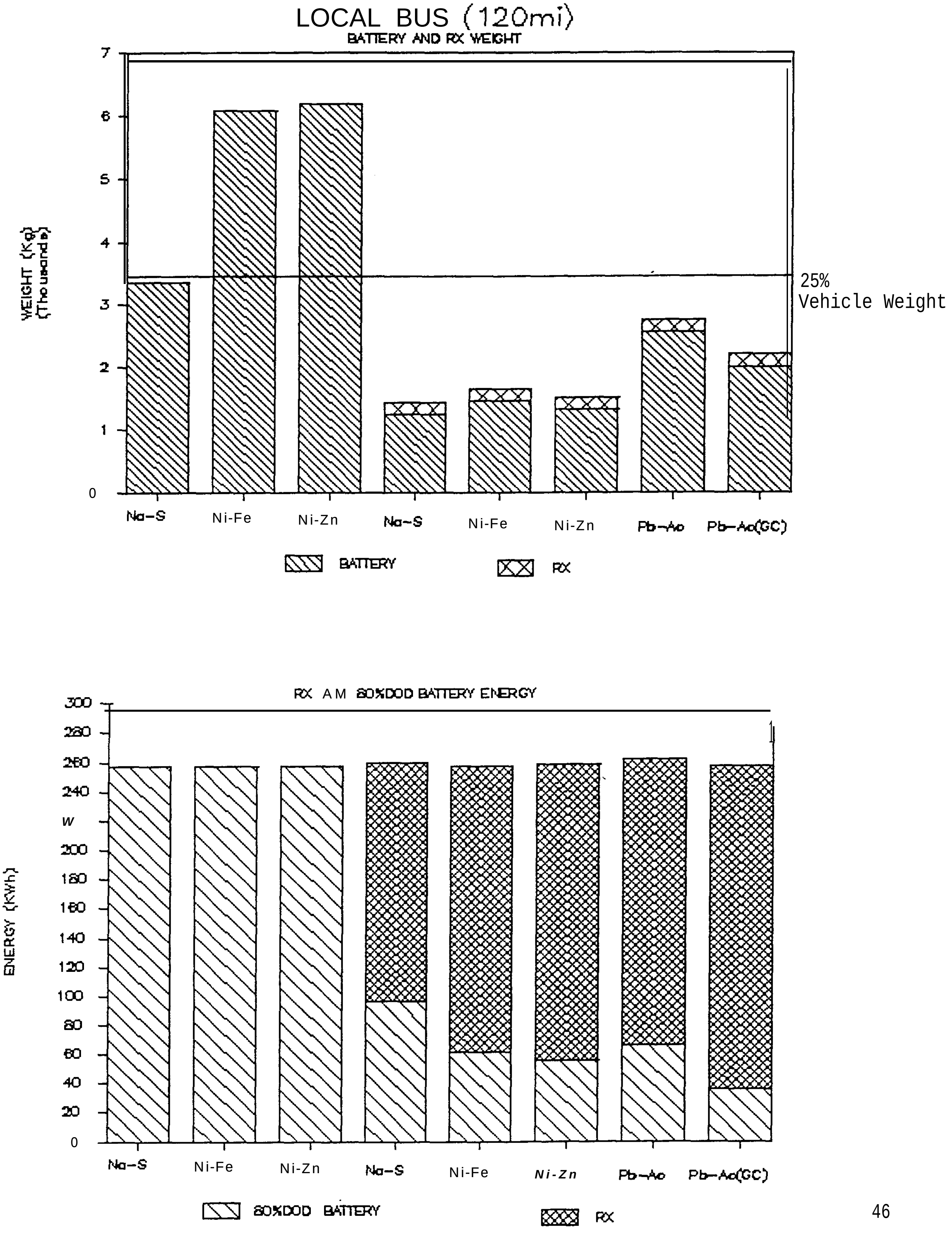
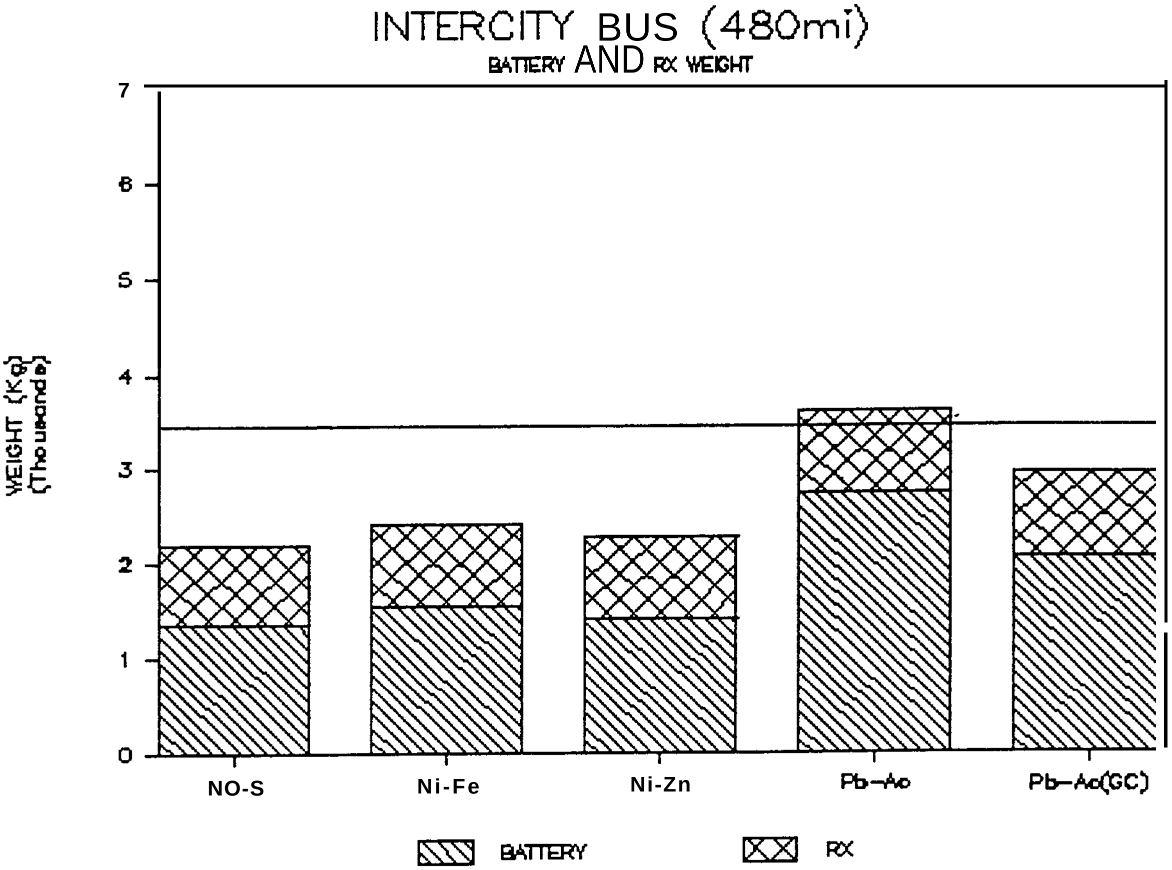


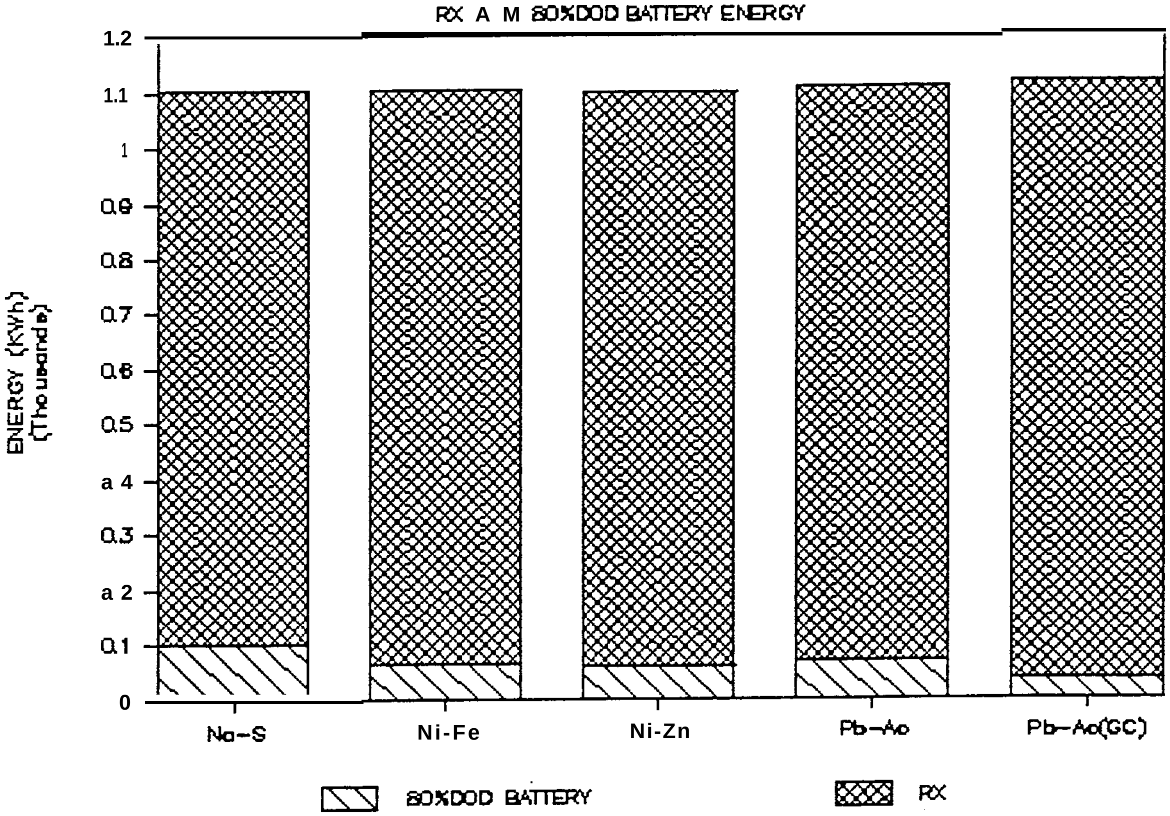
FIGURE 15: BUS DESIGNS FOR THE INTERCITY SCENARIO



INTERCITY BUS (480mi)

BATTERY AND RX WEIGHT

25%
Vehicle Weight



RX A M 80%DOD BATTERY ENERGY

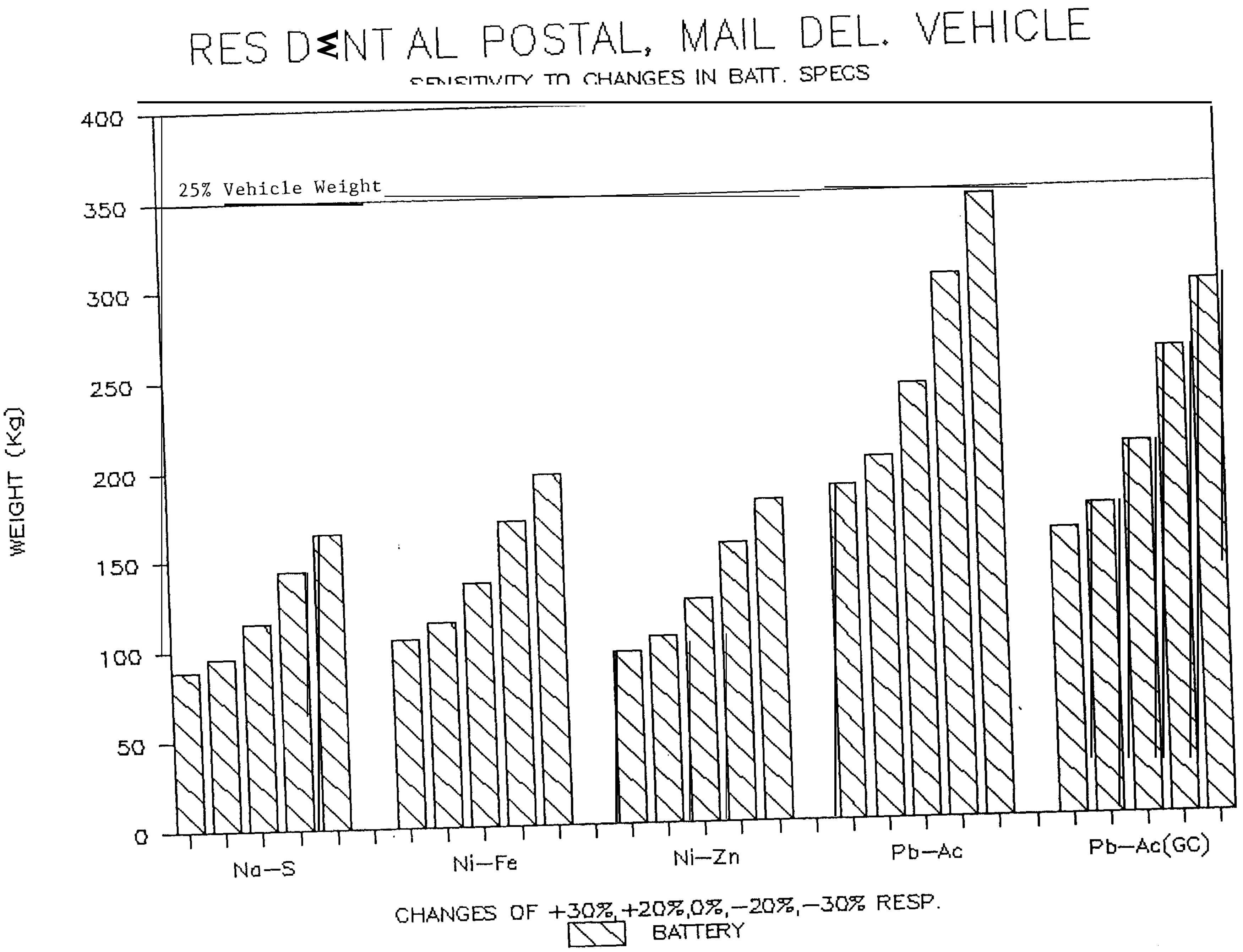


FIGURE 16: SENSITIVITY OF THE RESIDENTIAL POSTAL VEHICLE DESIGNS

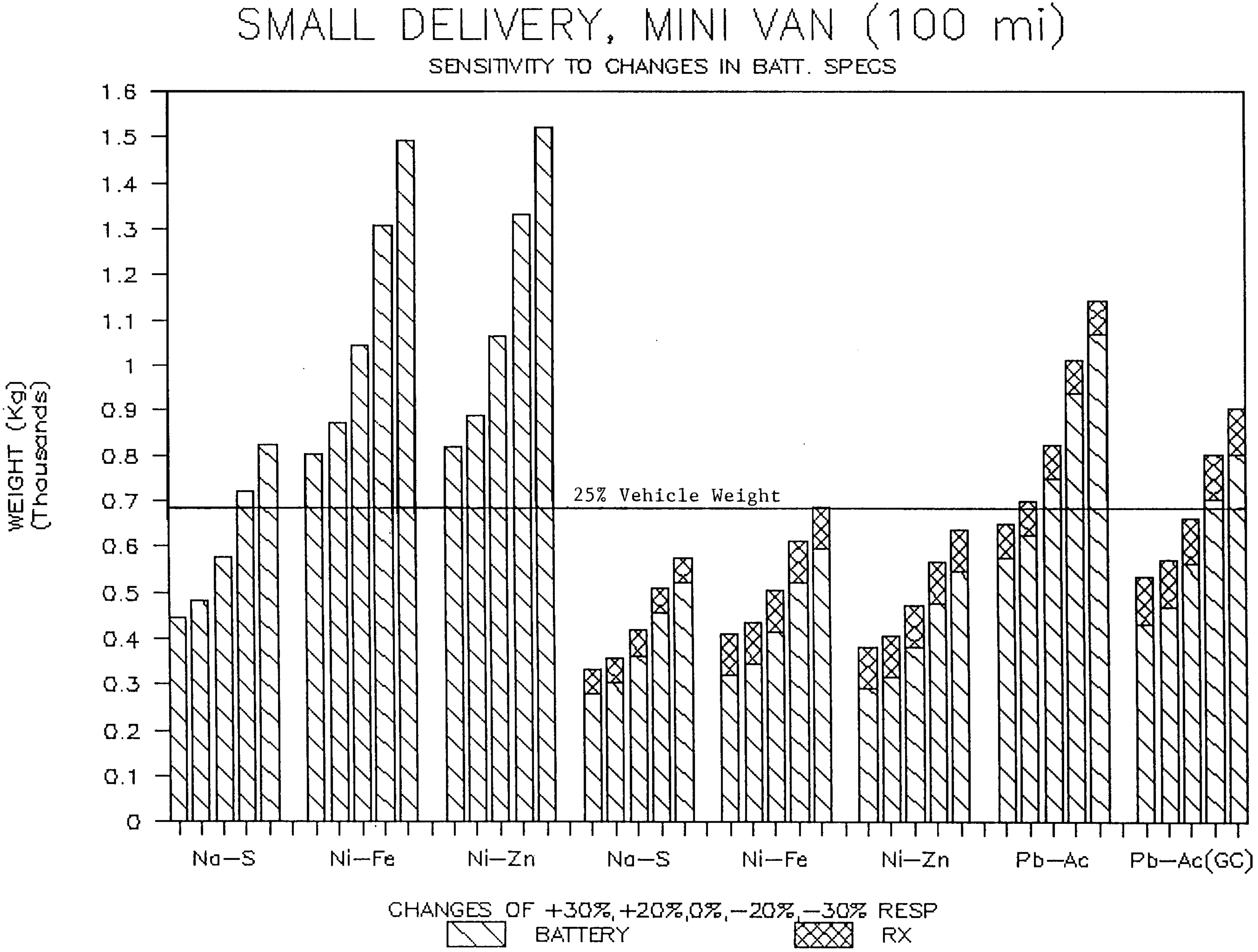


FIGURE 17: SENSITIVITY OF THE SMALL DELIVERY SCENARIO MINI VAN DESIGNS

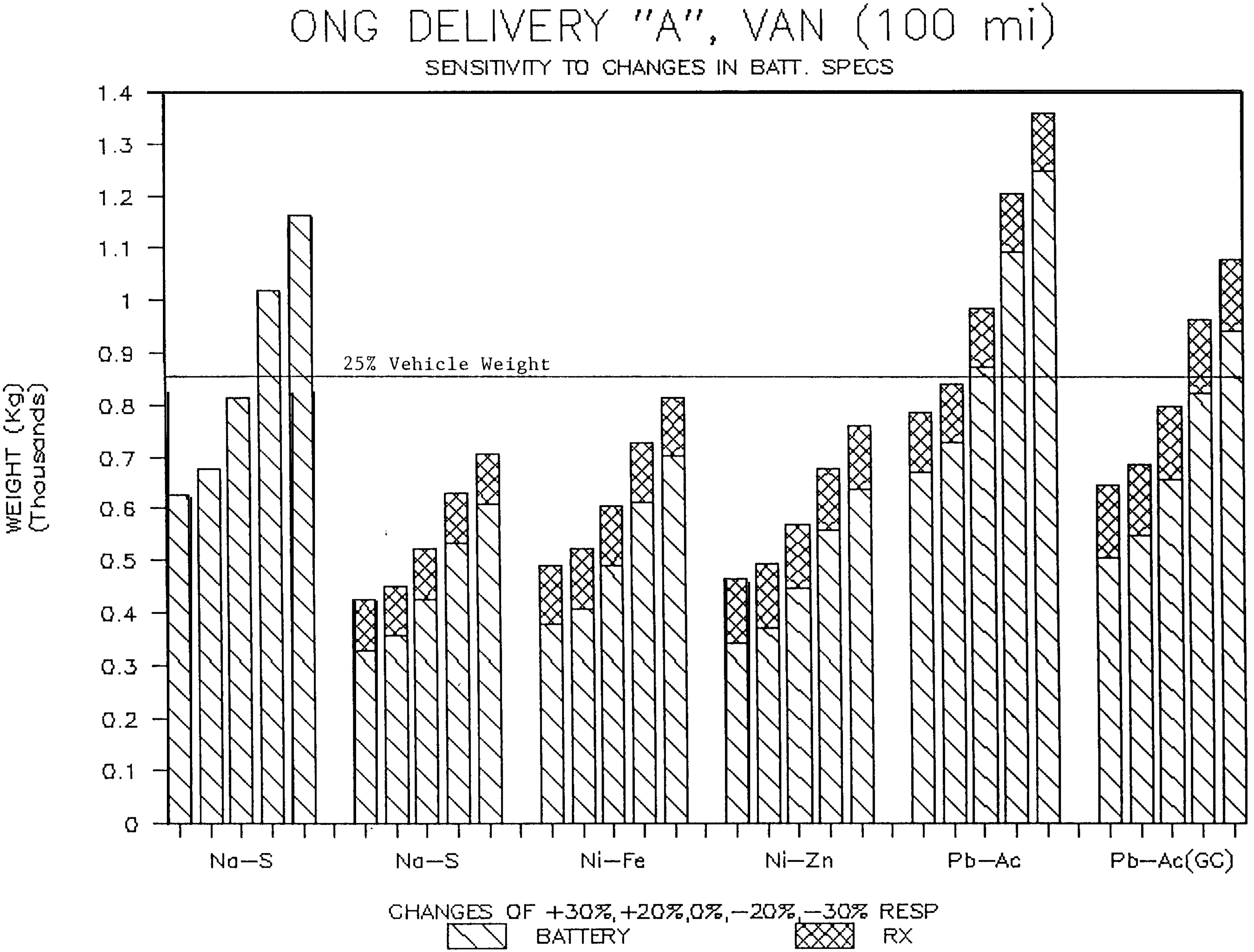


FIGURE 18: SENSITIVITY OF THE LONG DELIVERY (100 miles)
VAN DESIGNS

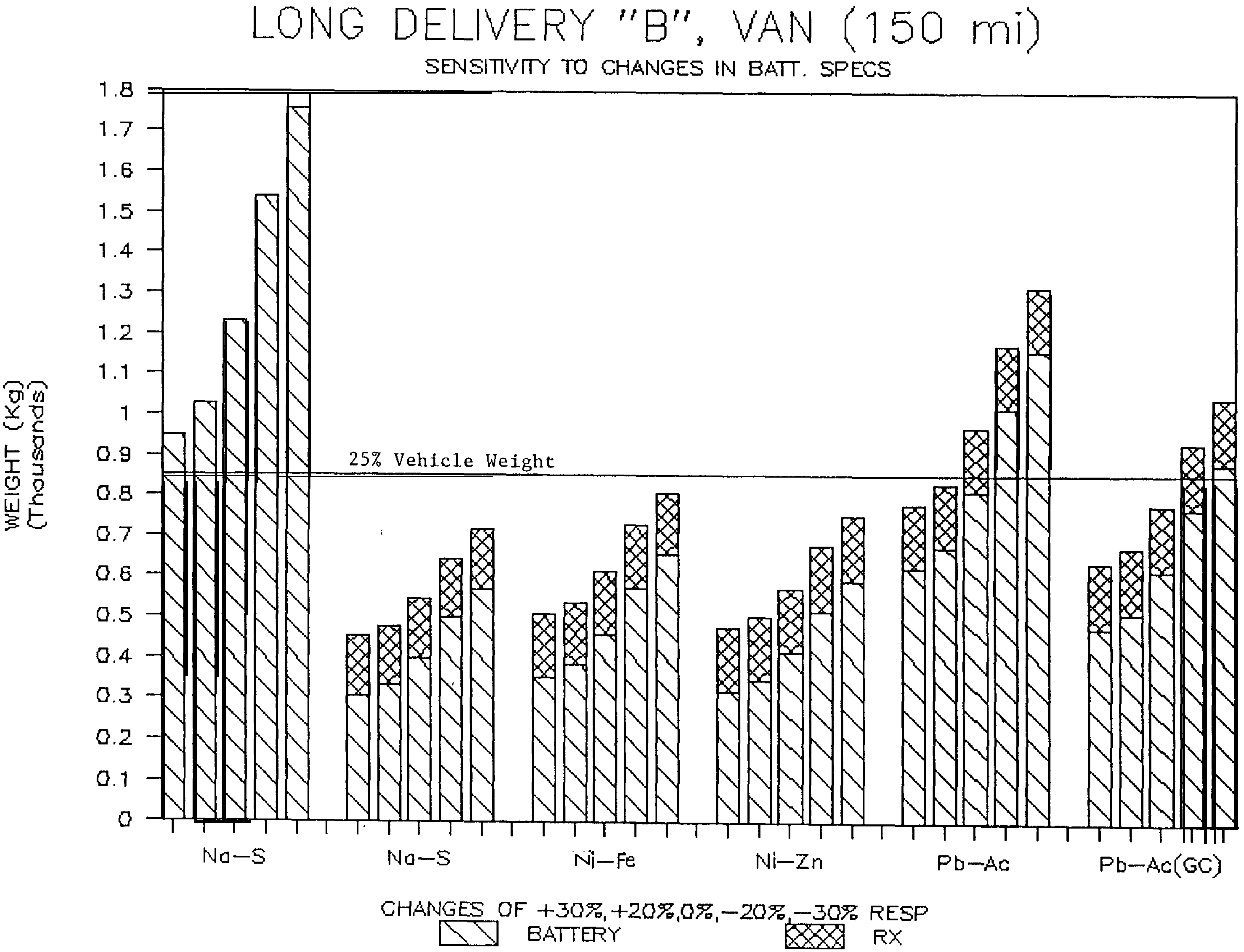


FIGURE 19: SENSITIVITY OF THE LONG DELIVERY (150 miles)
VAN DESIGNS

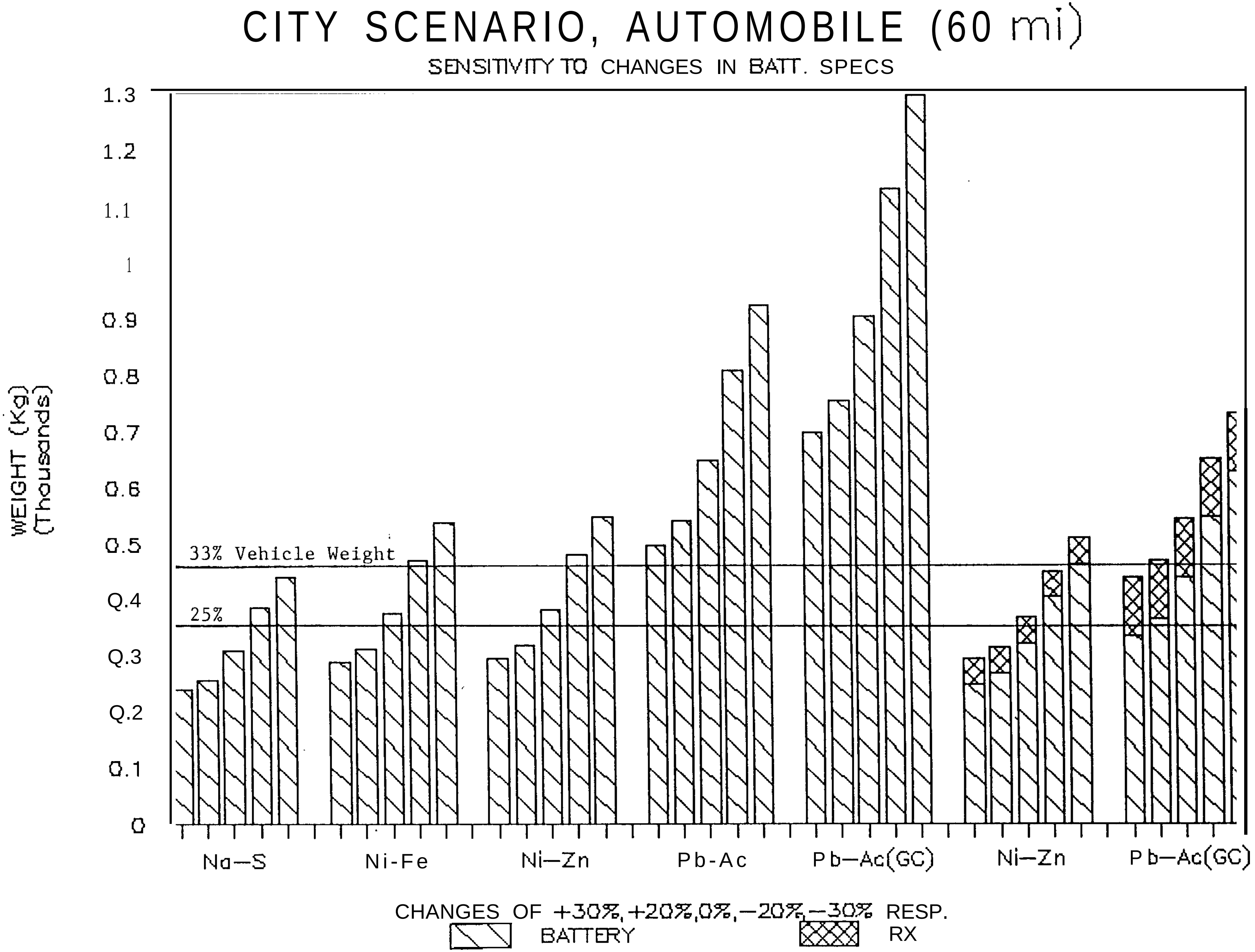


FIGURE 20: SENSITIVITY OF THE CITY SCENARIO AUTOMOBILE

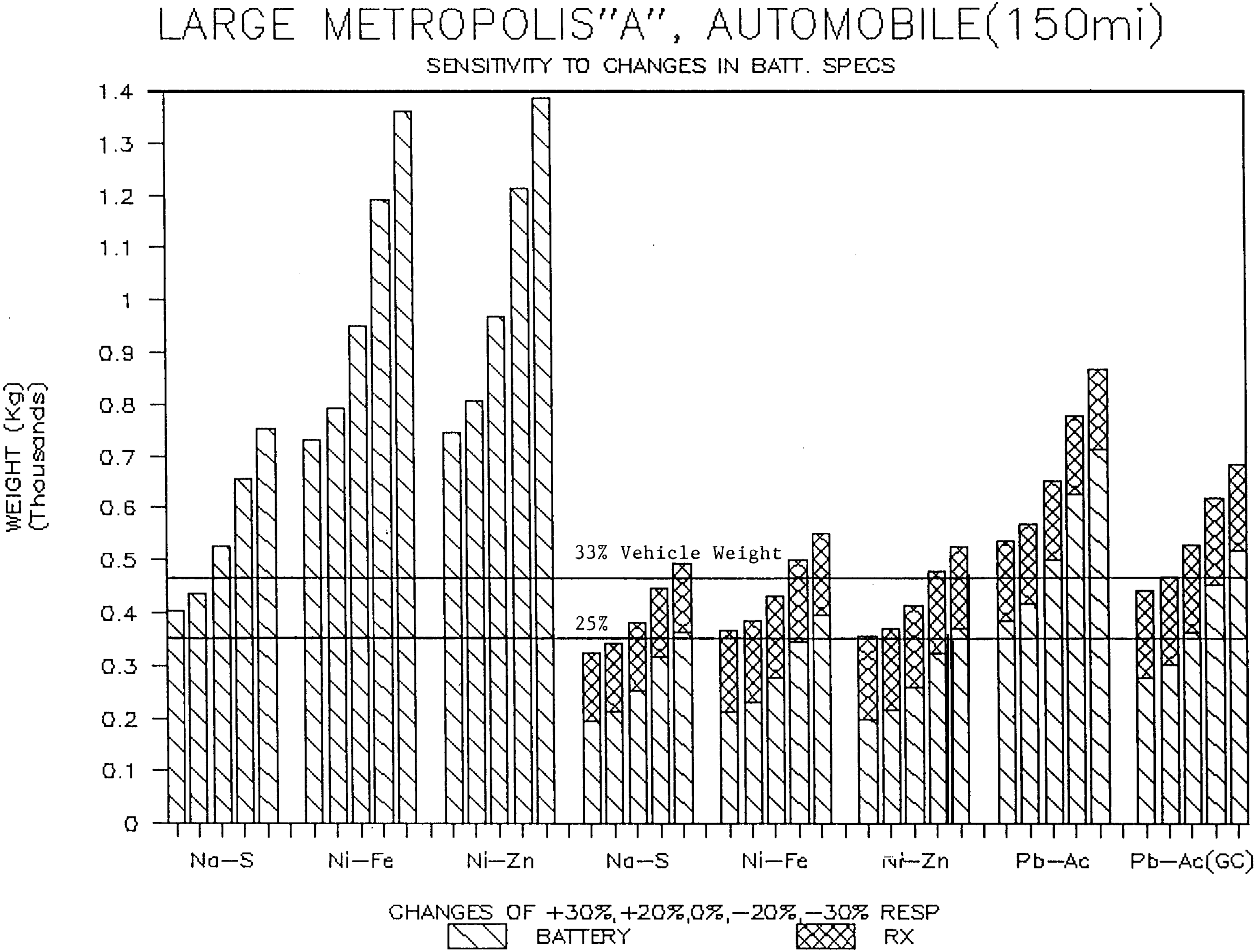


FIGURE 21: SENSITIVITY OF THE LARGE METROPOLIS (150 miles) AUTOMOBILE DESIGNS

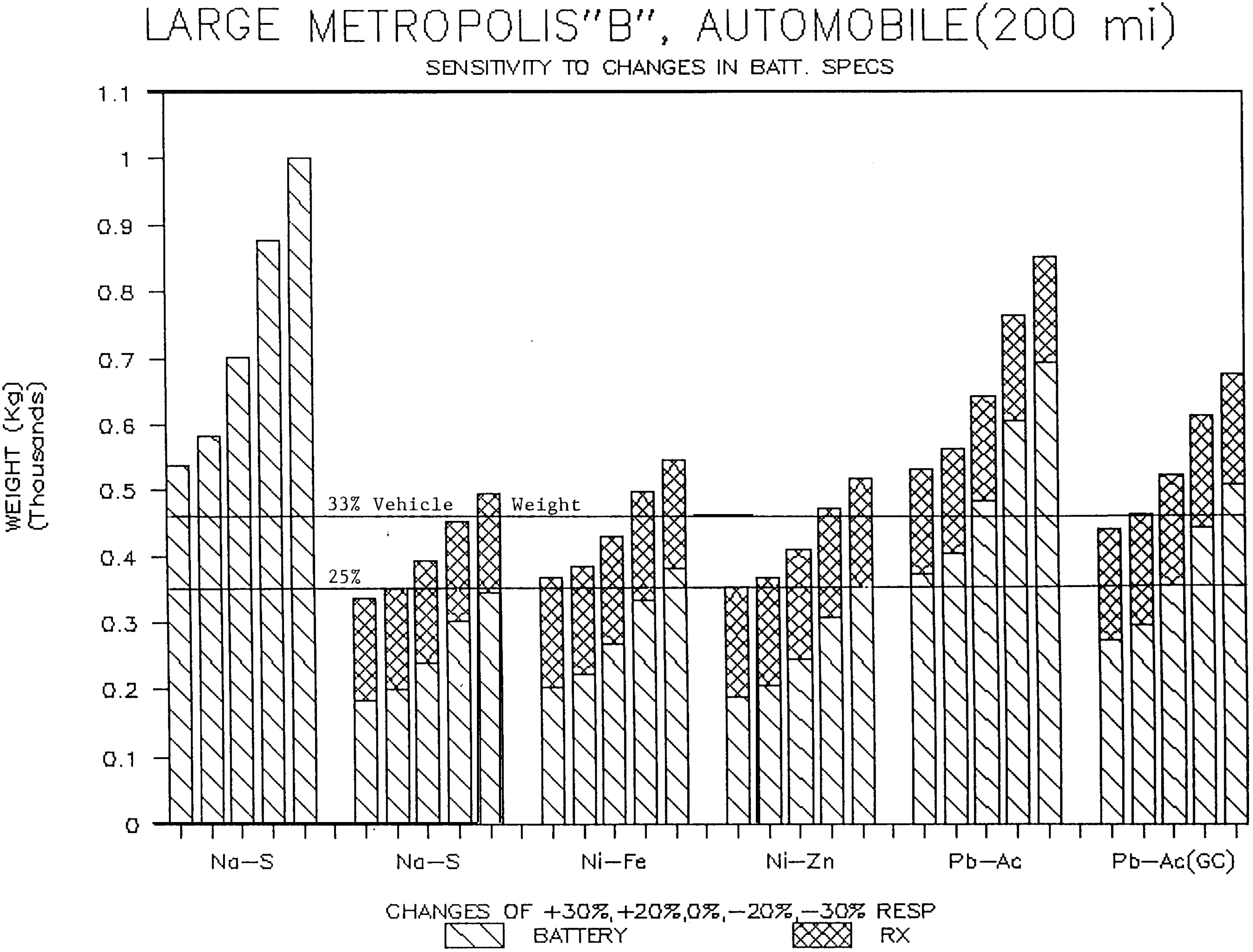


FIGURE 22: SENSITIVITY OF THE LARGE METROPOLIS (200 miles) AUTOMOBILE DESIGNS

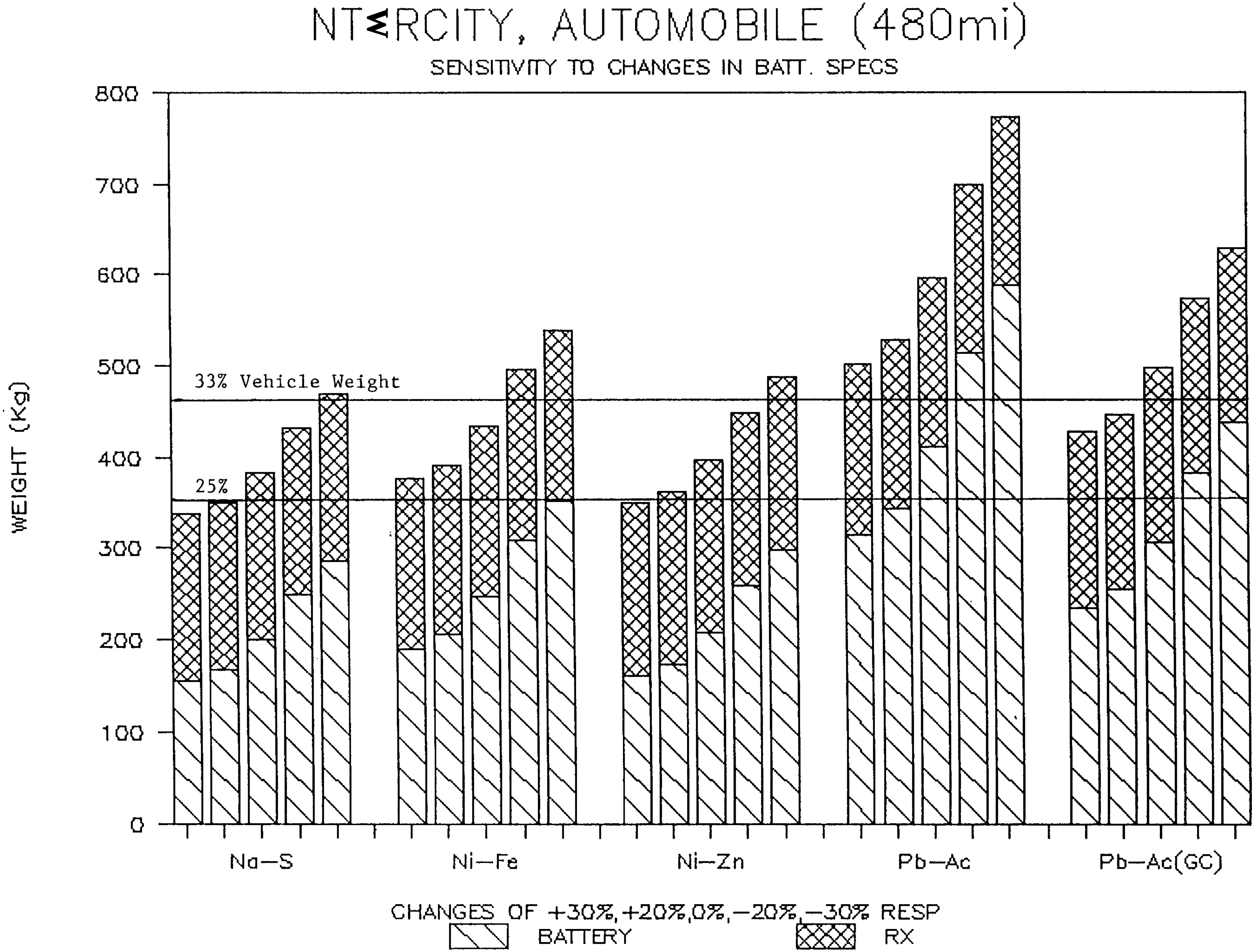


FIGURE 23: SENSITIVITY OF THE INTERCITY AUTOMOBILE DESIGNS

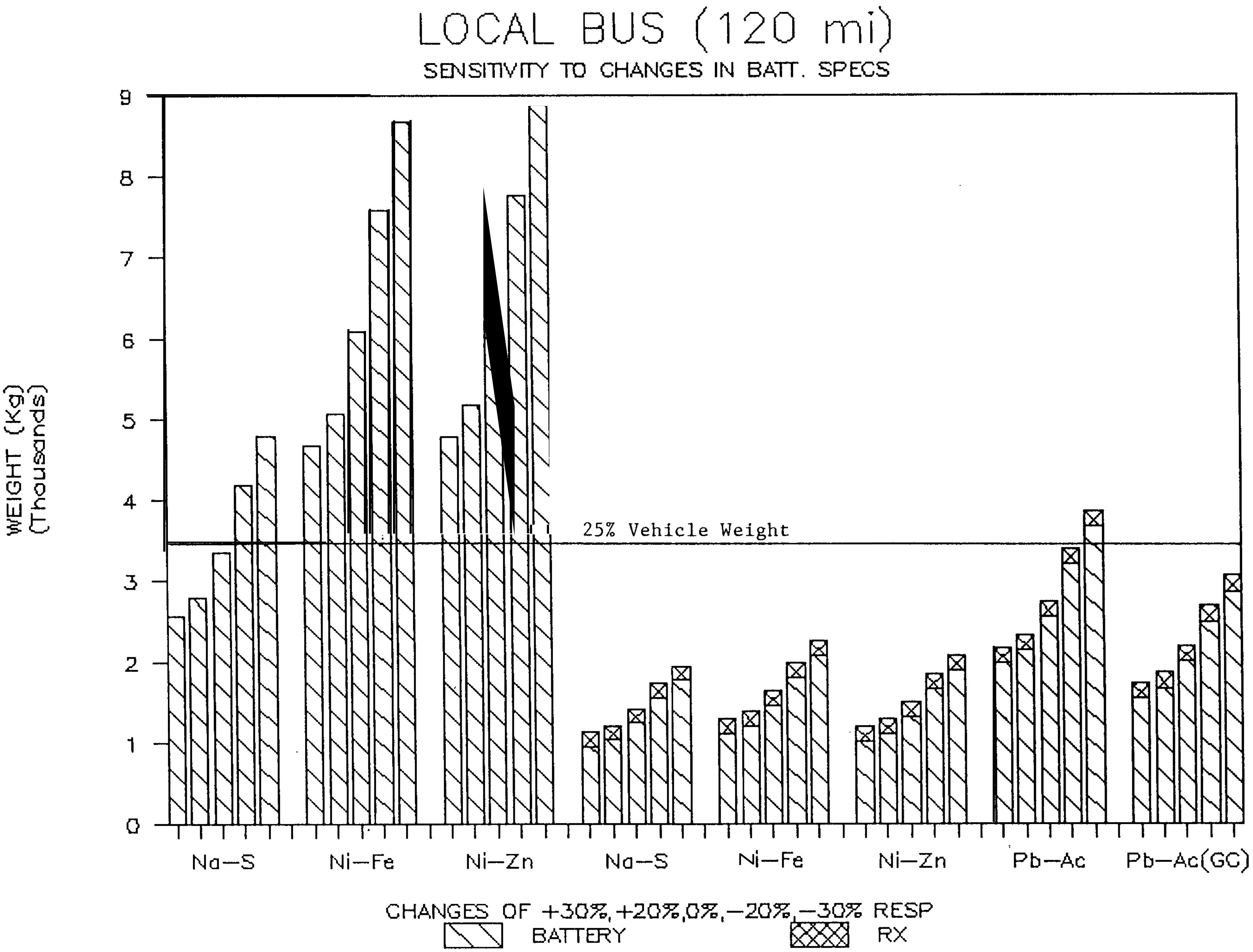


FIGURE 24: SENSITIVITY OF THE LOCAL BUS DESIGNS

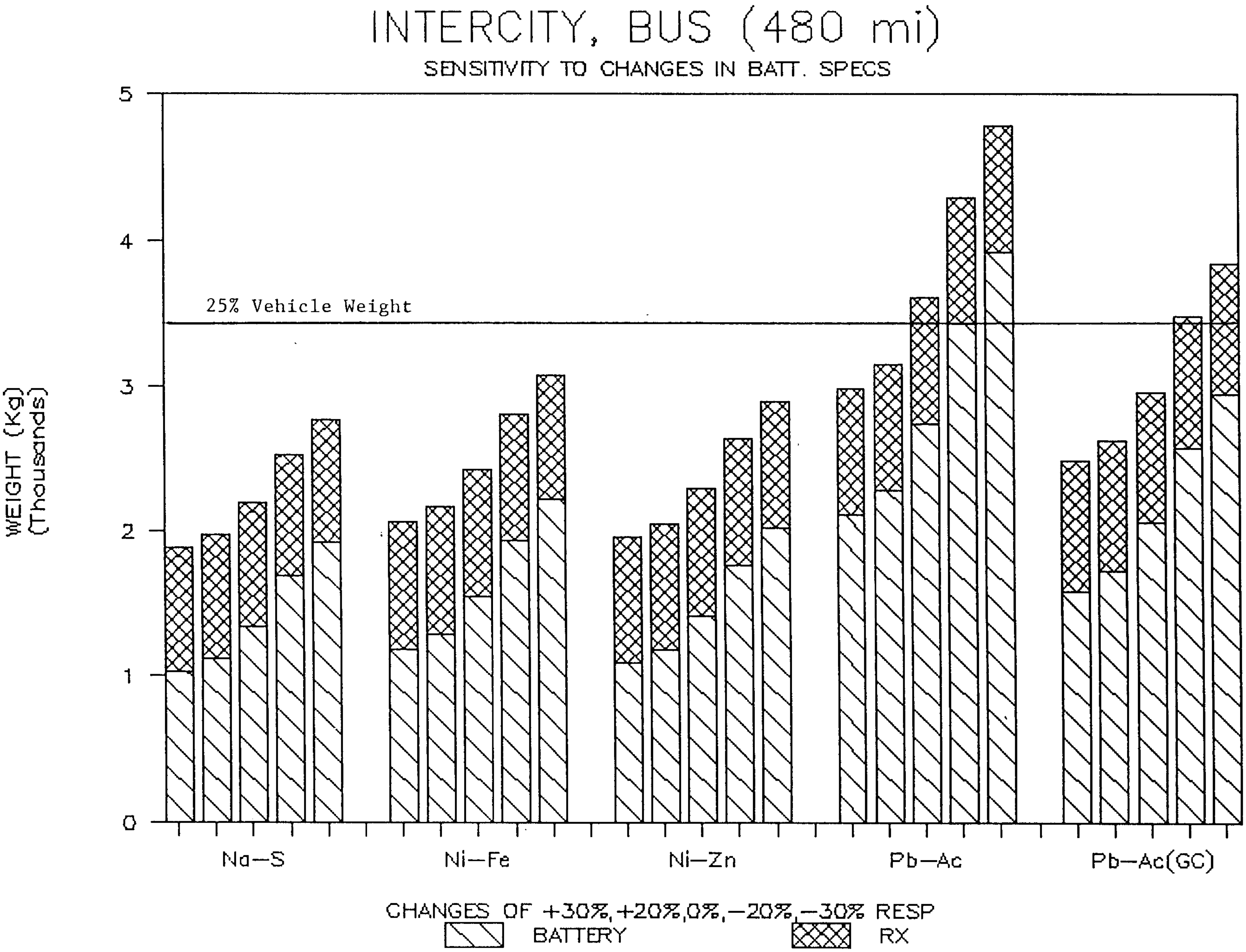


FIGURE 25: SENSITIVITY OF THE INTERCITY BUS DESIGNS

battery weight needed is substantially affected by changes in the battery characteristics.

Also, notice the asymmetric relationship in the graphs, in the sense that the weight reduction obtained for a given percentage improvement in battery technology is always smaller than the weight increase for the same -percentage deterioration in battery performance.

Comparing the sensitivity of EVs and HVs, the battery weight in both changes by the same mass fraction, but since EVs require more battery weight, the amount of kilograms changed in EVs is always greater than the ‘amount changed in HVs. This makes EVs more sensitive to changes in battery technology than HVs.

Studying the designs for each of the scenarios, no drastic changes are observed, in the sense that the designs that were over the target weight by large margins are still infeasible even with the 30% battery improvement. But, special attention should be given to those designs that were over or under the target weight by small margins (e.g. most of the automobile designs with advanced batteries) because changes in battery characteristics can have a huge impact by making the designs appropriate or not.

In general, the most robust designs to changes in battery characteristics are the following:

- All the electric vehicle designs for the residential postal scenario.
- The Na-S, Ni-Fe and Ni-Zn hybrid designs for the small delivery mini van, long delivery van and intercity bus.
- Na-S, Ni-Fe, Ni-Zn and Pb-Ac(GC) hybrids for the local bus scenario.

All the sensitivity values can be found in Appendix D.

7. **AIR CONDITIONING**

Air conditioning has usually been ignored by electric vehicle developers because of its serious impact on driving range. However, it is likely to be essential for any commercially viable vehicle design.

The present study therefore includes sizing the battery (or battery and RX) in such a way that the vehicles can provide A.C. and still reach the driving ranges specified by the already defined driving scenarios.

7.1 AIR CONDITIONING REQUIREMENTS

The A.C. power requirement assumed for the selected vehicle for each driving scenario is listed in Table 16.

The cooling requirement for a compact car was found to be 3.76 KW for a 100 degrees Fahrenheit and 20% relative humidity conditions [lo]. In the same report, it was found that by reducing the amount of fresh air through the blower system, the power required could be reduced to 2.58 KW. Based on this data, an intermediate value of 3 KW was chosen for the automobile designs. Other A.C. power requirements worth discussing are the ones used for the intercity bus and the local bus. The ASHRAE Handbook (American Society of Heating, Refrigerating and Air Conditioning Engineers) [1 1] indicates that for an intercity bus traveling at 60 mph, outside conditions typical of the United States give A.C. loads from 12 to 23 KW. For an urban bus, the cooling loads are greater because the bus may carry a crush load of standees and the fresh air load is greater due to the number of door openings. The cooling capacity required therefore ranges from 20 to 35 KW. Intermediate values of 20 KW and 28 KW were selected for the intercity and local buses respectively for the analysis to follow.

7.2 BATTERY AND RANGE EXTENDER SIZING METHOD FOR VEHICLES WITH AIR CONDITIONING

To size the battery and RX for the different designs, a similar procedure to the one discussed in Section 6.2 was performed. The only difference is that the total energy that needs to be supplied by the battery (or battery+RX) now includes the energy to provide air conditioning. The worst possible case, using the air conditioning for the total driving time, was used to estimate the energy required.

A sample of the spreadsheet used for the designs with A.C. can be

TABLE 16: AIR CONDITIONING POWER REQUIREMENT FOR THE DIFFERENT VEHICLES

	A.C. Power
MAIL DELIVERY VEHICLE	2.50 KW
MINI VAN	3.50 KW
FULL SIZE VAN	3.75 KW
AUTOMOBILE (Compact)	3.00 KW
LOCAL BUS	28.0 KW
INTERCITY BUS	20.0 KW

found in Table 17. Notice that all the designs were planned to go to 80% battery DOD by the end of the duty cycle day.

7.3 VEHICLE DESIGNS WITH AIR CONDITIONING

Figures 26 to 35 will be used to describe the most appropriate vehicle designs with air conditioning for each of the driving scenarios. Each of the figures shows the designs previously suggested (without A.C.) and the new designs (with A.C.) so that comparisons can be made. All the exact values can be found in Appendix E.

The residential postal vehicle designs with air conditioning are shown in Figure 26. Notice that hybrid designs, which were not appropriate for vehicles without air conditioner, are now good options. This is reflected especially in both Pb-Ac designs? which would go over the target weight as electric vehicles. Another interesting point is the striking difference between the EVs with and without A.C. based on Na-S and Pb-Ac(GC). The reason why the Na-S electric design with A.C. changes so little with respect to the one without A.C. is that the design without A.C. had to be sized to meet the power requirement and had extra energy. Now this extra energy is applied towards air conditioning. On the other hand, the Pb-Ac(GC) without A.C. needed to be sized to meet the energy requirement and now needs a large amount of additional battery to supply the energy needed for A.C.

The mini van designs for the small delivery scenario are shown in Figure 27. Notice the difference in the changes that are necessary in EVs and HVs to provide air conditioning. Electric vehicles experience a large increase in battery weight while hybrid vehicles only experience a small increase in weight. Taking a closer look at the weight of the hybrids, the RX weight has increased with respect to the designs without A.C.(due to the larger output power needed) and the battery weight has decreased so that the energy and power requirements can be met in the optimal way (again, optimal in the sense that the requirements are met without any extra energy or power). The meaningful result of adding A.C. is that electric vehicles are no longer an option, because not even with Na-S would the battery weight stay below the target weight. The ratings of the RXs needed range from 6 to 8.5 KW. Compared to the RXs used for the vehicles without A.C. (2.5 to 5 KW) a difference of 3.5 KW is found, indicating that the 3.5 KW A.C. load falls directly on the RX.

Similar results are found for the van designs for the long delivery (A) and (B) scenarios. Figure 28 show that four hybrids (Na-S, Ni-Fe, Ni-Zn and Pb-Ac gel cell) make it below the target weight. Minimal changes in

TABLE 17: BATTERY AND RANGE EXTENDER SIZING SAMPLE FOR VEHICLE DESIGNS WITH AIR CONDITIONING

```
DESIGNS:  SMALL DELIVERY, MINI VAN
W/ AIR CONDITIONER          (100mi)

Energy?            31.04     (@ n=0.25)
Transm.Eff?         0.70
A.C. Power?          3.5 Kw
Total Energy =     69.79 KWh

Power?              50.0 Kw

Driving time?       7.27 h
Veh.Weight?         2720 Kg
Veh.Weight/4 =       680 Kg (Target battery and rx weight)

EV:
Designed for 80% DOD of the battery.

Na-S  (CSPL)                        909 Kg     87.2 KWh   118.1 KW
Ni-Fe (NIF225)                     1646 Kg     87.2 KWh   181.1 KW
Ni-Zn (Delco-Remy)                 1678 Kg     87.2 KWh   201.3 KW
Pb-Ac (EV-5T)                      2726 Kg     87.2 KWh   169.0 KW
Pb-Ac (GC-6V-200)                  3965 Kg     87.2 KWh   317.2 KW

HV:
Designed for 80% DOD of the battery.
Na-S  (CSPL)                        341 Kg     32.7 KWh    44.3 KW
rx                                  113 Kg     43.6 KWh     6.0 KW
                               -------------------------------------
                                    454 Kg     76.3 KWh    50.3 KW


Ni-Fe (NIF225)                      386 Kg     20.5 KWh    42.5 KW
rx                                  139 Kg     54.5 KWh     7.5 Kw
                               -------------------------------------
                                    525 Kg     75.0 KWh    50.0 Kw


Ni-Zn (Delco-Remy)                  367 Kg     19.1 KWh    44.0 Kw
rx                                  139 Kg     54.5 KWh     7.5 KW
                               -------------------------------------
                                    506 Kg     73.6 KWh    51.5 KW


Pb-Ac (EV-5T)                       685 Kg     21.9 KWh    42.5 KW
rx                                  139 Kg     54.5 KWh     7.5 Kw
                               -------------------------------------
                                    824 Kg     76.5 KWh    50.0 Kw


Pb-Ac (GC-6V-200)                   519 Kg     11.4 KWh    41.5 KW
rx                                  150 Kg     61.8 KWh     8.5 KW
                               -------------------------------------
                                    669 Kg     73.2 KWh    50.0 Kw
```

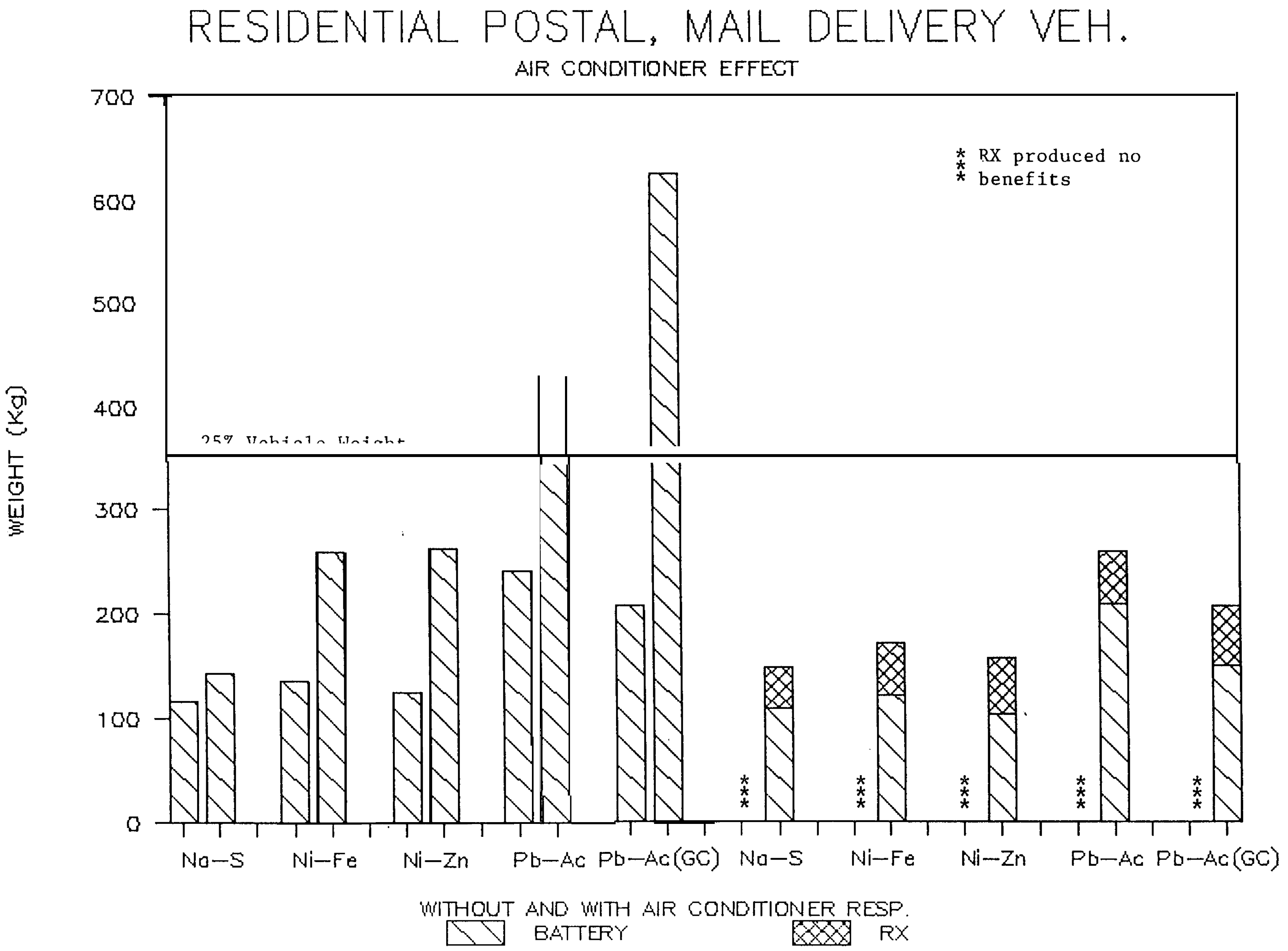


FIGURE 26: RESIDENTIAL POSTAL VEHICLE DESIGNS W/A.C.

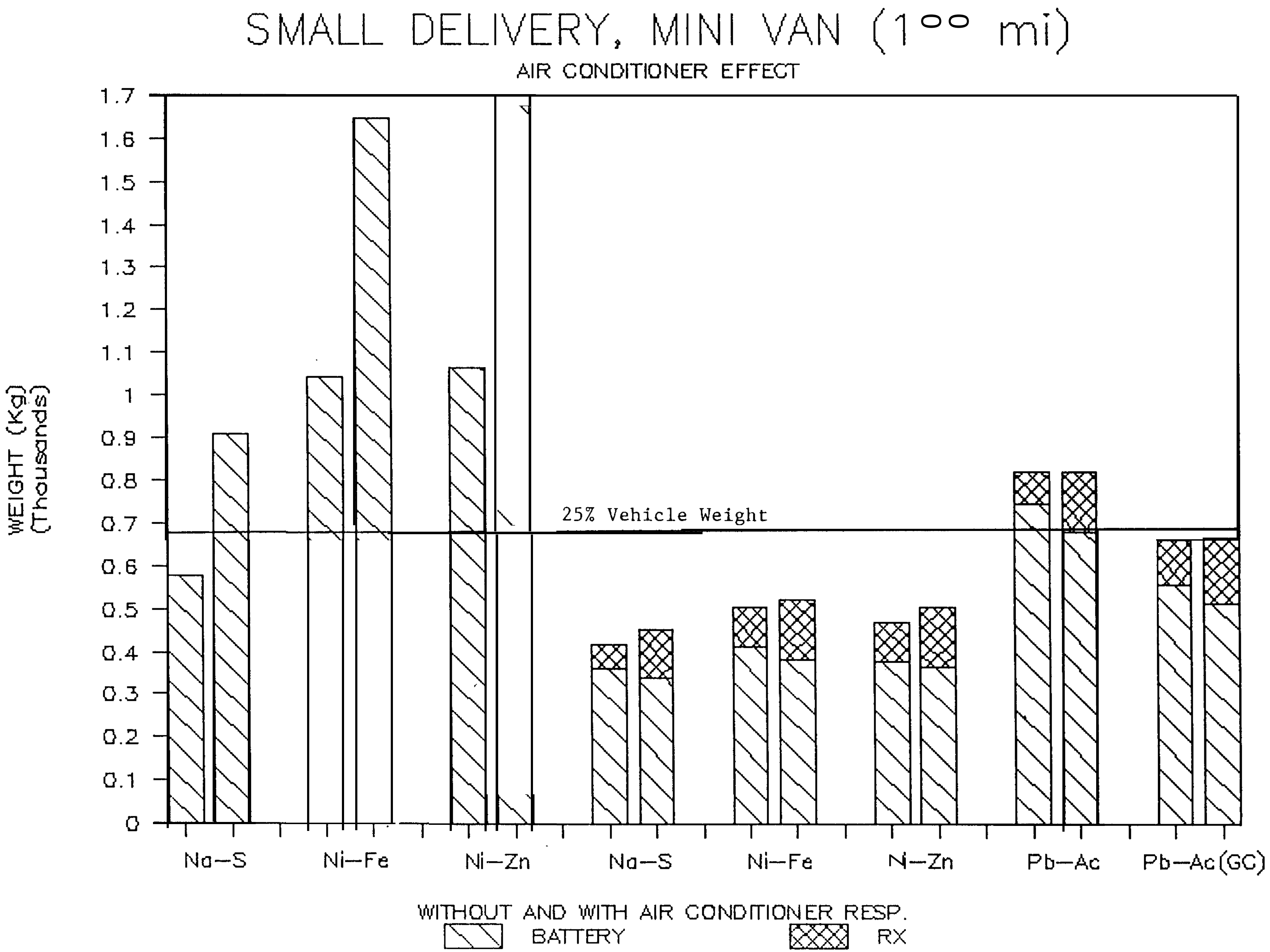


FIGURE 27: MINI VAN DESIGNS W/A.C. FOR THE SMALL DELIVERY SCENARIO

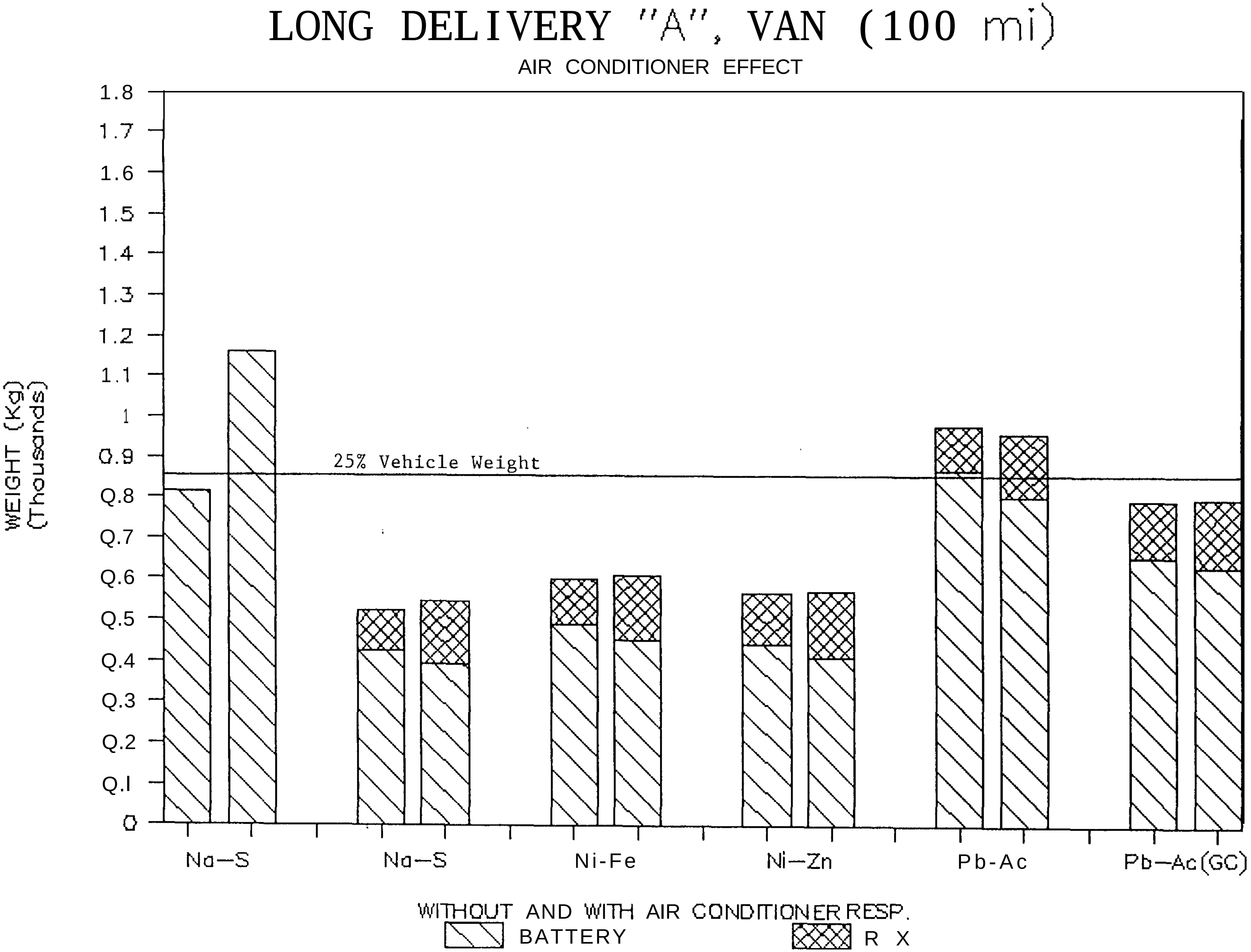


FIGURE 28: VAN DESIGNS W/A.C. FOR THE LONG DELIVERY SCENARIO (100 miles)

weight are experienced by hybrids, while the Na-S electric vehicle is now over the target weight due to a change of more than 300 Kg. The RX output powers are now from 8.5 to 11 KW compared to the previous 4.5 to 7.5 KW used for the designs without air conditioning.

For the 150 mile long delivery scenario (Figure 29), the van designs are hybrids based on the same battery technologies as the ones used for the previous scenario of 100 miles. Furthermore minimal weight changes of 2 to 25 Kg are needed to add the extra 50 miles. As expected, the RX output power had to be increased to 12 to 14.5 KW, bringing with it an increase in RX weight, but the battery weight decreased to appropriately meet the energy and power requirements. Sometimes, the increase in weight associated with an increase in RX output power is smaller than the decrease in weight associated with a reduction in battery needed, explaining why some designs with A.C. weigh less than their corresponding counterparts without A.C.

The automobile designs for the city scenario are shown in Figure 30. Notice that the electric vehicles based in Na-S weigh exactly the same with and without air conditioning. This is because the designs without A.C. had to be sized to meet the power requirement and had enough extra energy to provide air conditioning. Also, notice that Ni-Fe and Ni-Zn hybrids are possible, since there is enough weight reduction to bring the designs with A.C. under the target weight when compared with pure electric vehicles using the same batteries.

The automobile designs for the two large metropolis scenarios (150 and 200 miles) are shown in Figures 31 and 32 respectively. The best options for these two scenarios are hybrids based on the most advanced batteries (Na-S, Ni-Fe and Ni-Zn). Similar to previous results. the additional 50 miles can be achieved with a minimal penalty in weight’ (approx. 5 Kg). This includes the weight increase associated with the increase in RX output power and the weight reduction in battery needed. The RX power needed for these designs range from 10.5 to 13 KW for the 150 mile scenario, and from 12 to 14 KW for the 200 mile scenario.

The automobile designs for the 480 mile intercity scenario in Figure 33 again show hybrids based on the most advanced battery technologies. Notice how large is the mass fraction corresponding to the RXs, which range from 17.5 to 18.5 KW. Just as shown in the design section for vehicles without air conditioning, most of the energy comes from the RXs. Pure electric operation with air conditioning could be provided for days where 27 miles or less are desired.

The advantages of the RX could not be more clear than in the local bus

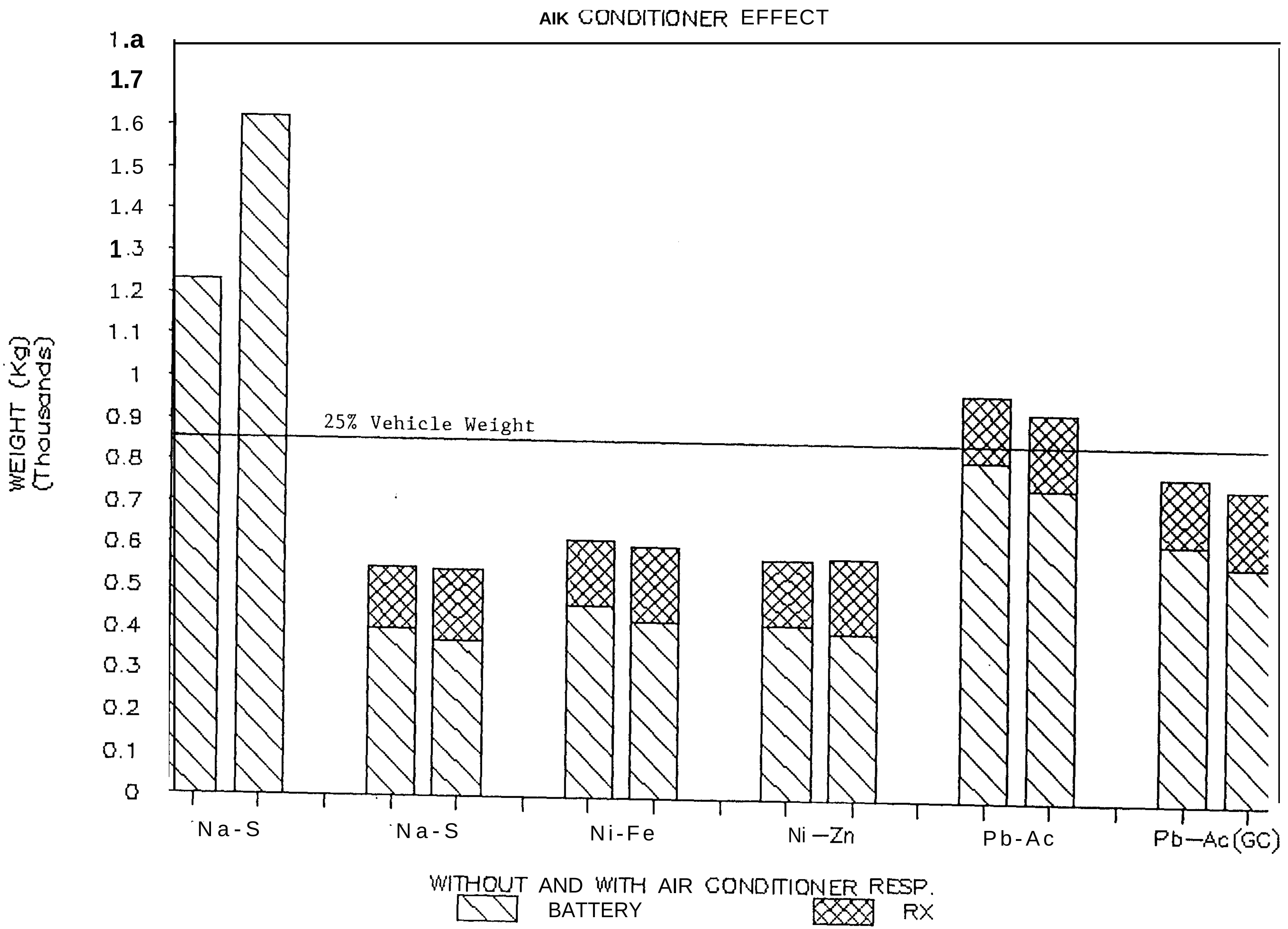


FIGURE 29: VAN DESIGNS W/A.C. FOR THE LONG DELIVERY SCENARIO (150 miles)

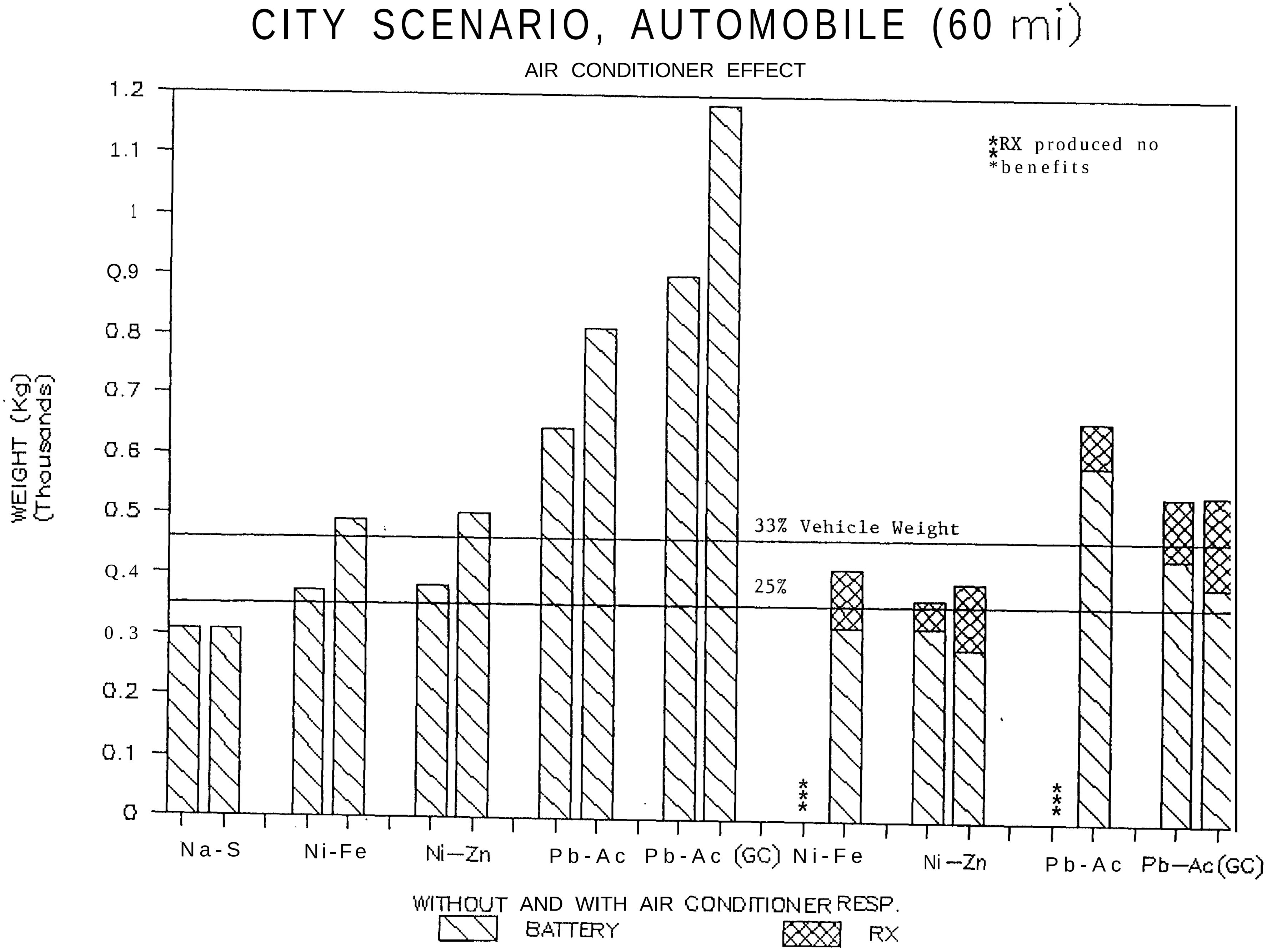


FIGURE 30: AUTOMOBILE DESIGNS W/A.C. FOR THE CITY SCENARIO

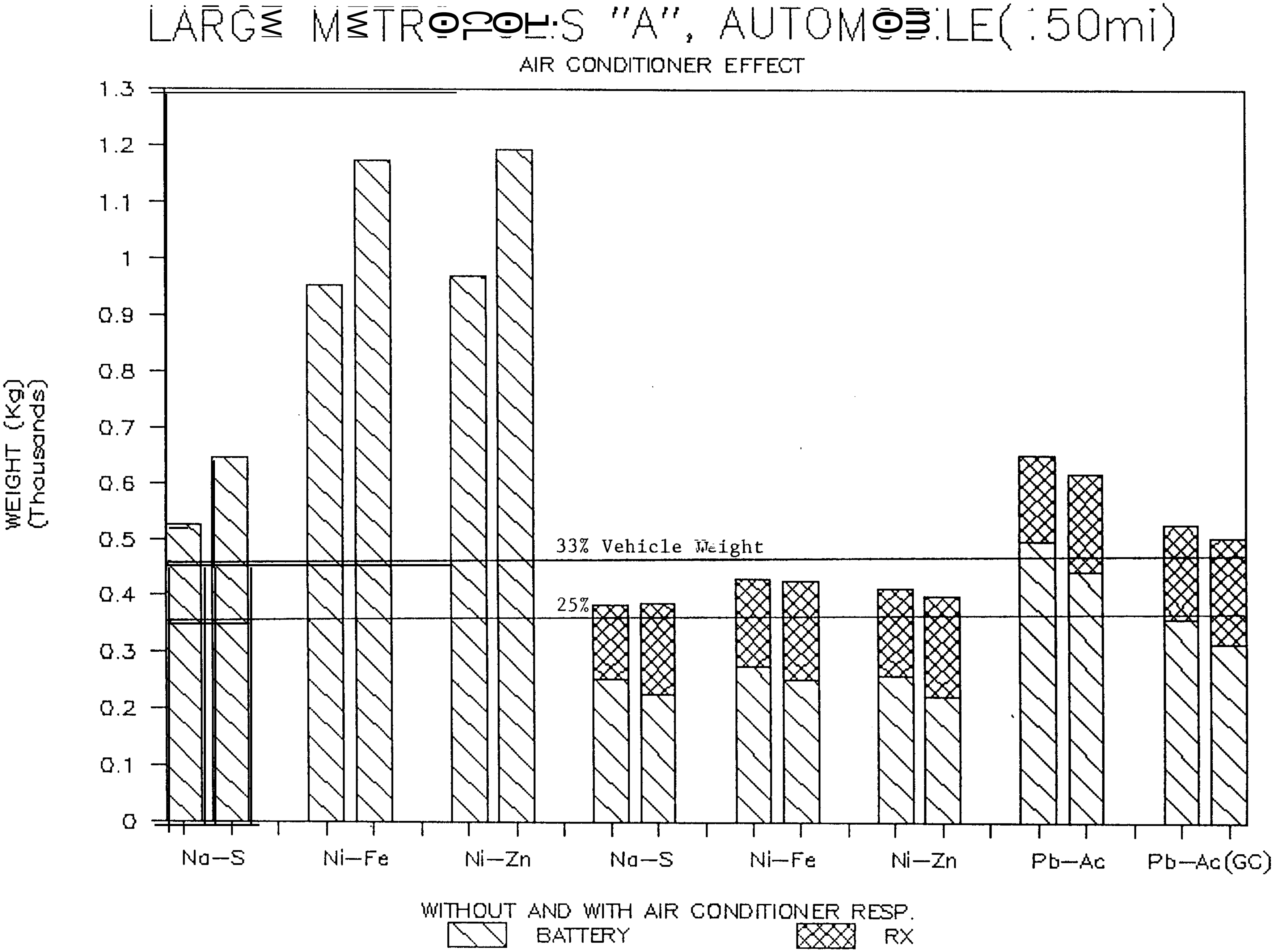


FIGURE 31: AUTOMOBILE DESIGNS W/A.C. FOR THE LARGE METROPOLIS SCENARIO (150 miles)

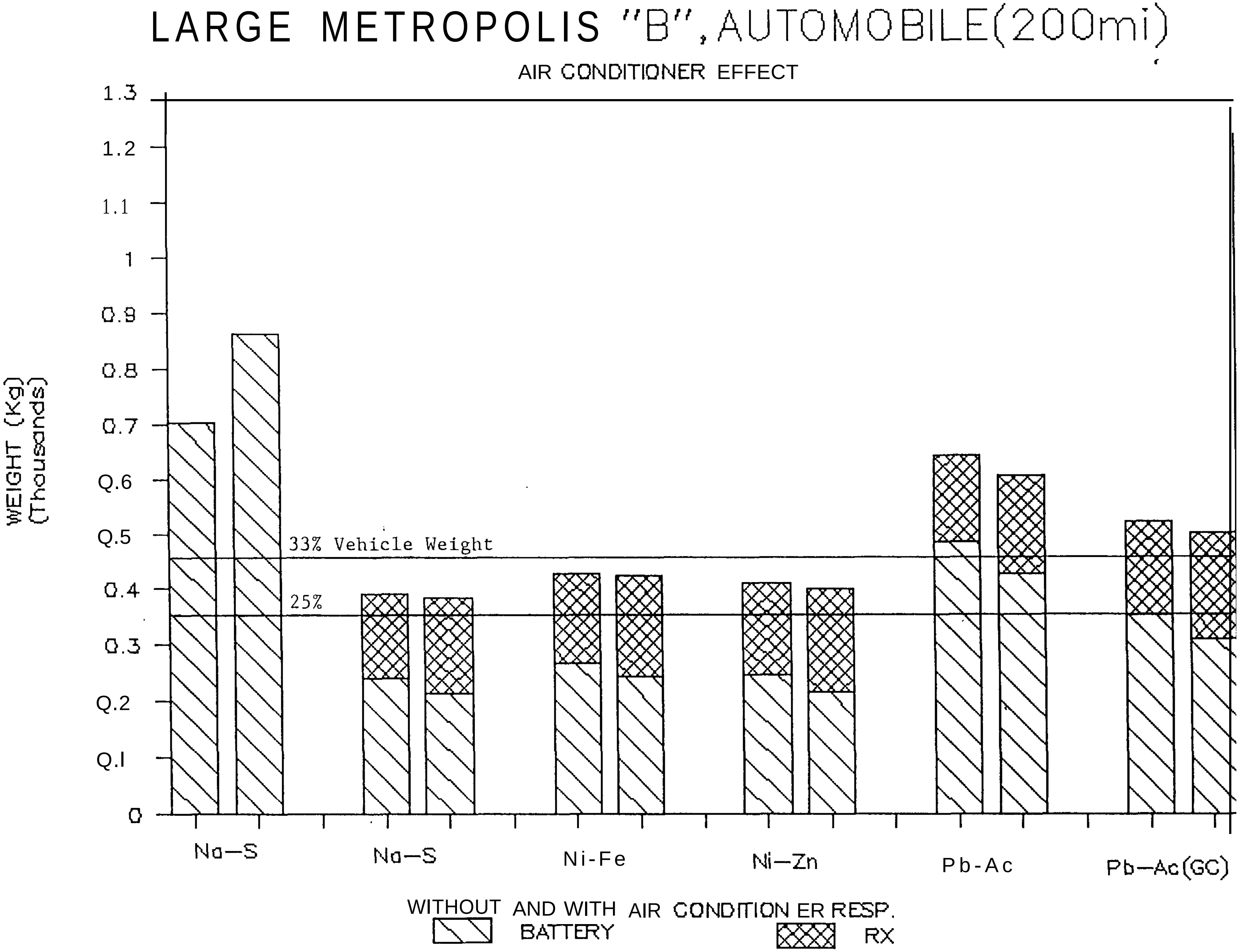


FIGURE 32: AUTOMOBILE DESIGNS W/A.C. FOR THE LARGE METROPOLIS SCENARIO (200 miles)

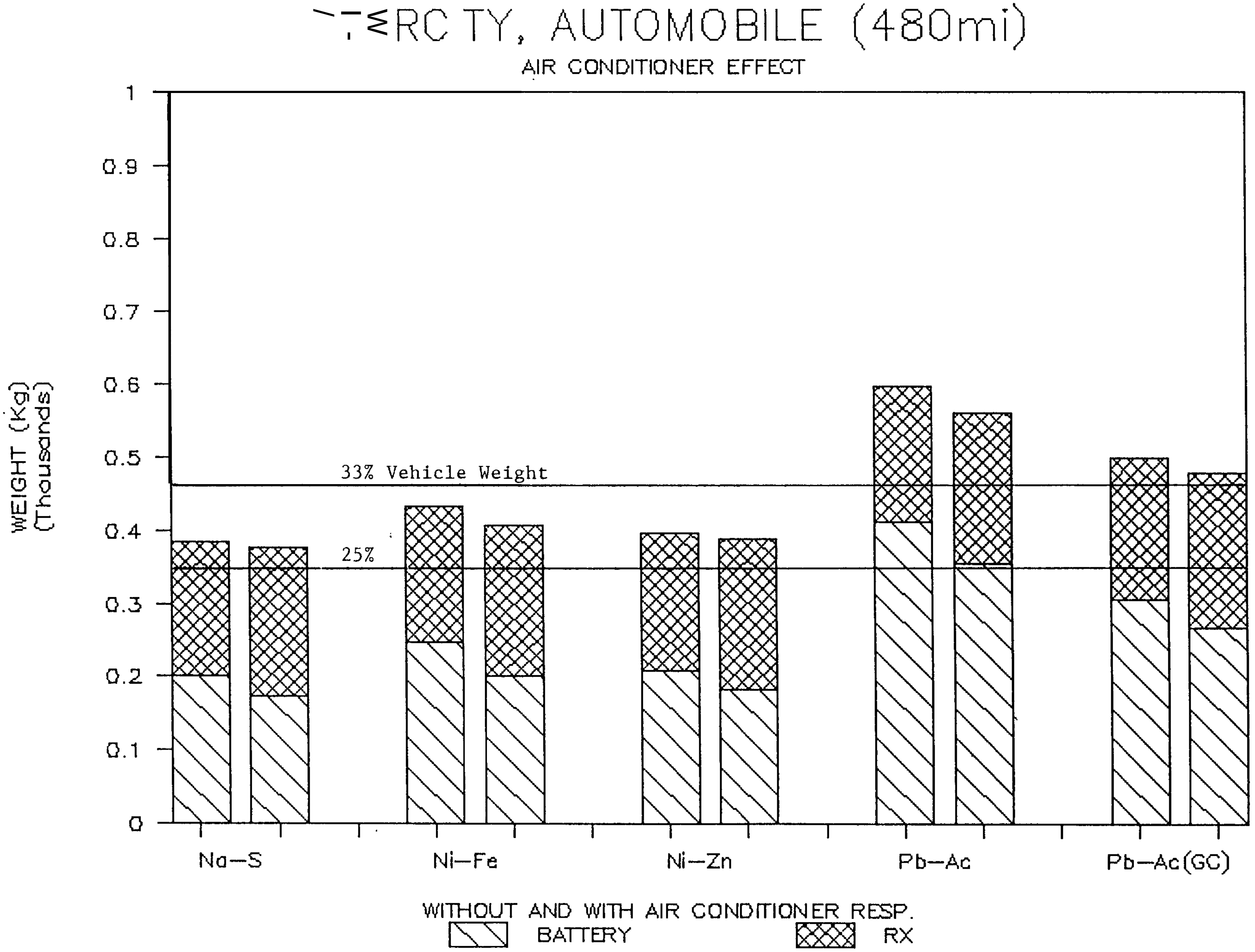


FIGURE 33: AUTOMOBILE DESIGNS W/A.C. FOR THE INTERCITY SCENARIO

scenario. In Figure 34 notice how much battery needs to be added to the pure electric vehicle to provide air conditioning. On the other hand, hybrid vehicles only require larger RXs, 42 to 46 KW. Any of the battery technologies analyzed could be used to implement a bus for this type of scenario. One curious finding is that by having the 28 KW air conditioning system working for the 13 hours involved in this scenario, the bus would actually spend more energy in cooling the passengers than in transporting them to another destination (one of the reasons being the long idling periods).

The designs for the intercity bus (Figure 35) are still questionable. The RXs required are now from 145 to 155 KW (195 to 205 hp) for this 300 KW bus. Nevertheless, adding the air conditioning only contributed 20 of those kilowatts.

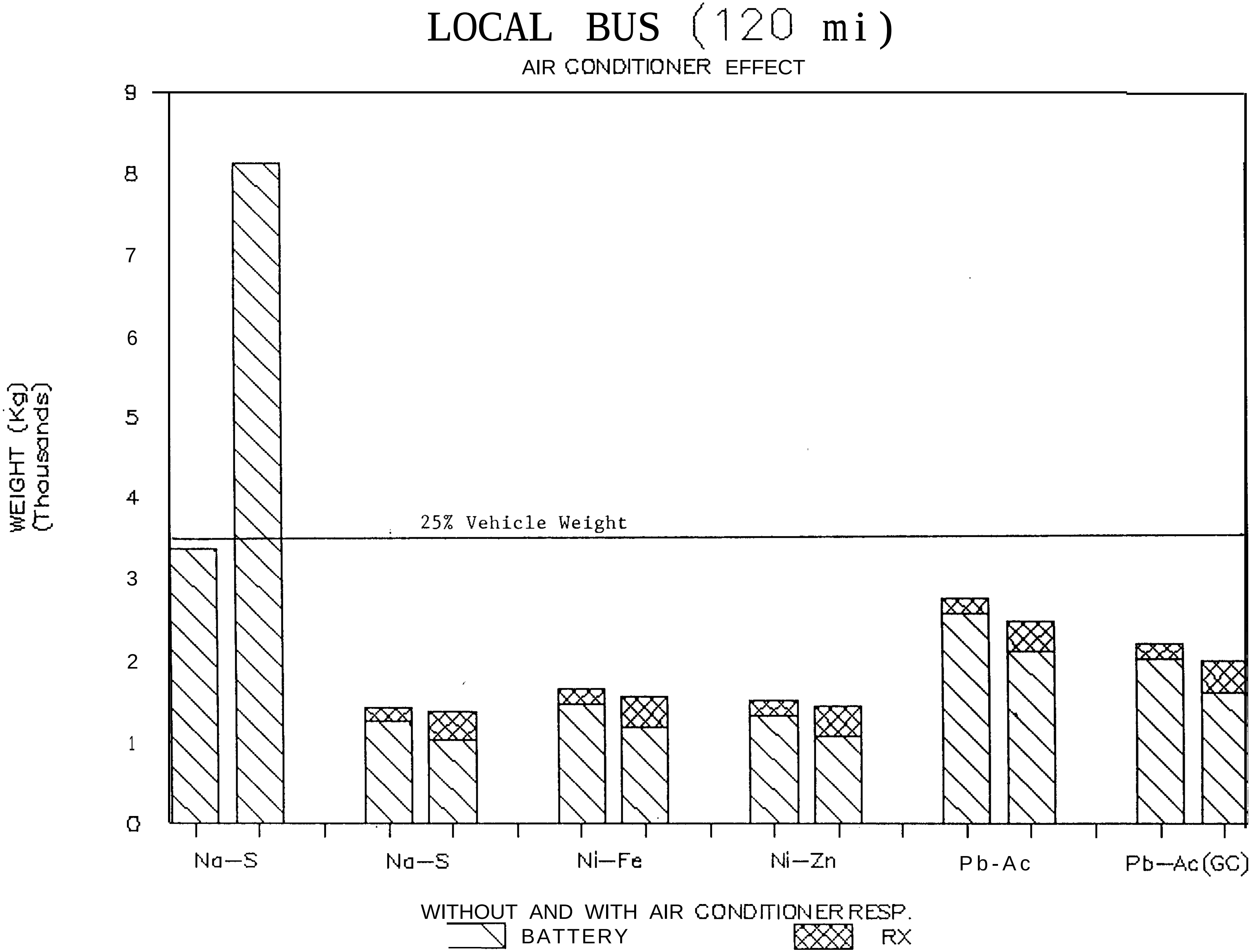


FIGURE 34: BUS DESIGNS W/A.C FOR THE LOCAL BUS SCENARIO

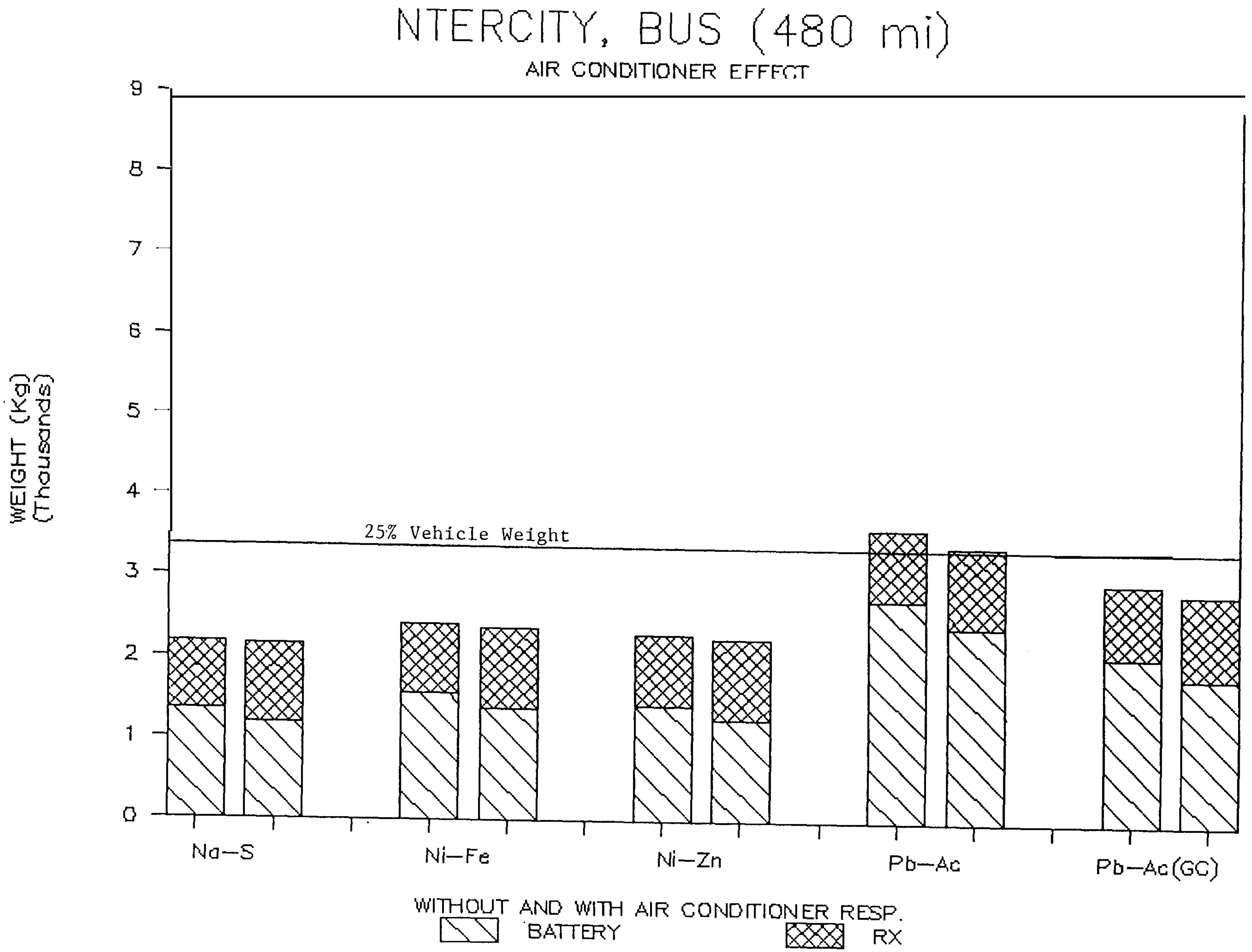


FIGURE 35: BUS DESIGNS W/A.C. FOR THE INTERCITY SCENARIO

8. ALTERNATE SIZING METHOD FOR HYBRID VEHICLES

The sizing method for hybrid vehicles used throughout this study was to size the battery and range extender in such a way that the energy and power requirements were met exactly (i.e., without any extra energy or power). An alternate method is to size the range extender to supply the average power required in the driving scenario and the battery to satisfy peak power demands. In the latter method, the average power required for each driving scenario can be found by dividing the total energy required by the driving time. The range extender output power is set to this average power. Then the battery is sized to provide the difference between the peak power requirement and the average power requirement. Notice that the power requirement (i.e., peak power) would be satisfied by the range extended and the battery together, while the range extender alone would satisfy the total energy requirement over the driving period. The amount of extra energy (unneeded energy available in this design is an amount equivalent to the energy stored in the battery.

Table 18 summarizes some of the results found by using sizing method I (the method used throughout this study) and method II (the alternate method that was explained in the previous paragraph) for each of the driving scenarios without air conditioning.

Notice that the differences between both sizing methods are minimal, especially the differences in total battery and range extender weight. Method I was selected because it favors smaller range extenders and the use of more battery. Although the differences are minimal, hybrids designed based on method I would run cleaner because battery operation is favored and the range extender provides less energy (and therefore less emissions).

Appendix F consists of the designs (battery mass and RX output power) that would be needed for each of the driving scenarios with and without air conditioning if method II were to be used to size the hybrid vehicles.

TABLE 18: COMPARISON OF HYBRIDS BASED ON DESIGN METHODS I AND II

		RX Power (Kw		Battery (Kg)		Battery+RX (Kg)	
		I	II	I	II	I	II
RESIDENTIAL POSTAL Mail Delivery Veh. (13 mi)	Na-S	0.0	1.5	115	104	115	149
	Ni-Fe	0.0	1.5	136	123	136	168
	Ni-Zn	0.0	1.5	125	113	125	158
	Pb-Ac	0.0	1.5	242	218	242	263
	Pb-Ac(GC)	0.0	1.5	208	169	208	214
SMALL DELIVERY Mini Van (100 mi)	Na-S	2.5	6.0	365	338	419	451
	Ni-Fe	4.0	6.0	418	400	508	513
	Ni-Zn	4.0	6.0	383	367	473	480
	Pb-Ac	3.5	6.0	750	710	824	823
	Pb-Ac(GC)	5.0	6.0	563	550	665	663
LONG DELIVERY "A" Van (100 mi)	Na-S	4.5	9.0	427	392	523	545
	Ni-Fe	6.0	9.0	491	464	604	617
	Ni-Zn	6.5	9.0	446	425	568	578
	Pb-Ac	6.0	9.0	871	823	984	976
	Pb-Ac(GC)	7.5	9.0	656	638	795	791
CITY SCENARIO Automobile (60 mi)	Na-S	0.0	10.0	308	231	308	390
	Ni-Fe	0.0	10.0	375	273	375	432
	Ni-Zn	1.5	10.0	323	250	368	409
	Pb-Ac	0.0	10.0	645	484	645	643
	Pb-Ac(GC)	5.0	10.0	438	375	540	534
LARGE METROPOLIS "A" Automobile (150 mi)	Na-S	7.0	13.0	254	208	384	385
	Ni-Fe	9.5	13.0	277	245	433	422
	Ni-Zn	9.5	13.0	260	225	416	402
	Pb-Ac	9.0	13.0	500	435	653	612
	Pb-Ac(GC)	11.0	13.0	363	338	528	515
INTERCITY Automobile (480 mi)	Na-S	14.0	16.0	200	185	383	380
	Ni-Fe	14.5	16.0	247	218	433	413
	Ni-Zn	15.0	16.0	208	200	397	395
	Pb-Ac	14.5	16.0	411	387	597	582
	Pb-Ac(GC)	15.5	16.0	306	300	498	495
LOCAL BUS (120 mi)	Na-S	12.5	20.0	1250	1192	1424	1411
	Ni-Fe	15.0	20.0	1455	1409	1644	1628
	Ni-Zn	15.5	20.0	1329	1292	1521	1511
	Pb-Ac	15.0	20.0	2581	2500	2770	2719
	Pb-Ac(GC)	17.0	20.0	2011	1938	2212	2157
INTERCITY BUS (480 mi)	Na-S	125	135	1346	1269	2188	2171
	Ni-Fe	130	135	1545	1500	2417	2402
	Ni-Zn	130	135	1417	1375	2289	2277
	Pb-Ac	130	135	2742	2661	3614	3563
	Pb-Ac(GC)	135	135	2063	2063	2965	2965

* All vehicle designs without A.C.

9. PRACTICAL LIMITATIONS OF EXISTING ENGINE-GENERATOR SETS

Specifications of engine-generator sets for recreational vehicle applications were requested from several current manufacturers [12-14] The information gathered shows that gasoline consumption in (gal/KWh) of current engine-generator sets seems to be independent of the size of the set (i.e. max. output power rating). Furthermore, an average value of 0.157 gal/KWh was observed, with all the different sets in a close region.

To give a general idea of the gasoline consumption and emissions of hybrid vehicles implemented with these engine-generator sets, a hybrid automobile based on the parameters of the Near Term Electric Test Vehicle "ETV-1" (vehicle mass = 1791 Kg, Cd=0.32, roll.res.coef.=0.009, frontal area= 1.84 m^2) was analyzed.

To find out how many miles per gallon of gasoline the vehicle would provide, the total energy consumption was calculated for different driving distances under SAE D cycles and under constant 60 mph travel. Short driving ranges (e.g. 60 miles) could be satisfied by the battery and a small energy contribution from the RX. Since little energy was needed from the RX, apparent fuel economy in mi/gal was excellent, 177 mi/gal for SAE D and 733 mi/gal at 60 mph. Note that this figure does not reflect the fact that a full battery charge was also consumed. Once the driving range increased, the contribution from the battery represented a smaller fraction of the total energy required and the energy from the RX accounted for most of it. Then, the fuel economy decreased sharply, reaching a lowest point of 28.5 mi/gal for the 480 mile driving range at 60 mph.

Since 480 mile trips are rare? and short daily trips are much more likely, the average mi/gal of the hybrid vehicle would be expected to be good (a full recharge is also needed). Nevertheless, long trips that depend almost solely on the engine-generator sets highlight the relatively high gasoline consumption of these engine-generator sets and the need to improve them.

Mobile source emissions of hybrid vehicles only depend on the emissions of the engine-generator set. There has been little or no effort to date to reduce the emissions of engine-generator sets, because there are no current exhaust emission standards for small utility engines. With the emission factors as reported by Roy A. Renner in [3] for the baseline engine and the "optimistic" engine (discarding dirty engines) the analyzed hybrid automobile based on the ETV-1 would not meet the current California nor EPA (Environmental Protection Agency) standards for automobile emissions. It would exceed the limits a few miles after the engine-generator set is turned on. If a 90% reduction in HC, CO and NOx emissions could be achieved by a 3 way catalytic converter, as suggested in [3], then all current standards could be met by the hybrid automobile independently of the driving distance by at least factors of 5 for HC, 4 for CO and 2.5 for NOx.

A comparison of overall emission factors (i.e., including the emissions produced at power plants to produce the electricity to recharge the battery) of this hybrid automobile with an internal combustion engine automobile is more complex and depends on a variety of factors such as what type of fuel or fuel mixture is used to generate the electricity, how stringent is the emission control imposed on the plant, how clean can the engine-generator run, how old is the catalytic converter used, etc.

The percent reduction in emissions per mile of EVs compared to IC vehicles was listed as 99.14% for HC, 99.65% for CO and 79.17% for NOx [15], for a moderately stringent control strategy, in the California system, in a 1995 scenario. (An increase in SOx and particulate matter was also reported but this increase is not as significant because transportation only contributes a small percent, 6% and 1.5%, of the total production of these two pollutants [15]). From these results, it can be seen that the electric part of hybrid vehicles leaves ample room for overall emission reductions, as long as the engine generator sets can be cleaned up.

In sumrnary, current engine-generator sets need to be more fuel efficient and cleaner. The current levels are far from what could be achieved because of the lack of incentives to increase their fuel efficiency and reduce their emissions. Thus far, the only concern has been to make them as cheap as possible.

The results discussed in this section can be found in Appendix G.

10. CONCLUSIONS

The residential postal scenario is optimal for EV technology. For a vehicle without A.C., battery life could be increased because the range could be reached without going into 80%DOD. It is not necessary to use the most advanced battery technologies due to the low energy requirement. If A.C. is desired, EVs based on Na-S, Ni-Fe and Ni-Zn would be the best. Other available options would be HVs based on Pb-Ac and Pb-Ac(GC).

The mini van for the small delivery scenario is a good application for a Na-S EV or for Na-S, Ni-Fe, Ni-Zn and Pb-Ac gel cell HVs. As hybrid vehicles, approximately 40 miles could be of pure battery operation, while the rest would be cleaner than regular I.C. mini vans because the RX would be running at its most efficient speed. For mini vans with air conditioning, HVs based in the same battery technologies could be implemented with almost no weight penalty. EVs would no longer be an option.

For the long delivery scenario van, Na-S, Ni-Fe, Ni-Zn and Pb-Ac gel cell HVs are the only alternatives if a 150 mile range is desired. If only a 100 mile range is desired, then a Na-S EV could also be an alternative. Adding air conditioning produces minimal weight penalties in the hybrids mentioned, because RXs with only somewhat larger output power are needed. EVs would no longer be an option.

For the city scenario automobile, for a 60 mile range, Na-S, Ni-Fe and Ni-Zn EVs are the best choices. Adding a RX produces no benefits. If air conditioning is desired, Na-S EVs or Ni-Fe and Ni-Zn HVs would be the best options. (Note: Ni-Fe and Ni-Zn EVs with A.C. are slightly over the battery target weight).

For the large metropolis automobile, for 200 mile range, with or without A.C., Na-S, Ni-Fe, and Ni-Zn HVs are the only available options, but the battery and RX together would weigh about l/3 of the total vehicle weight.

For intercity automobile travel, for 480 miles with or without A.C., the only options are Na-S, Ni-Fe and Ni-Zn HVs. Most of the range would come from the RX, but it could run cleaner than regular I.C. powered automobiles. Note that the user would not always drive 480 miles, and for days on which 40 miles or less are needed, these vehicles could offer pure battery operation. With A.C. on, they would offer 27 miles of pure electric operation.

The bus version of the intercity scenario is a more questionable application due to the large size of the RX needed (130 KW or 175 hp). Nevertheless, cleaner operation than conventional buses could be obtained. With air conditioning, the RX would have to range from 145 to 155 KW.

An optimal application for HVs is a local bus scenario. This application can be met by only adding a 12.5 to 17 KW range extender. The RX power is insignificant compared to the total power required for this bus. To provide air conditioning, the RX would be from 42 to 46 KW.

To see the conclusions in a tabular format refer to Table 18.

11. RECOMMENDATIONS

This report gave an overall view of the different market segments in which electric or hybrid vehicles could be used. From the technical point of view, the local bus scenario would be the best application for hybrid vehicle technology. On the other hand, if the application desired were one to which more people would relate, then a mini van or a van for a long range scenario would be the best. If an automobile application were to be selected, the automobile capable of going 480 miles would probably attract more users and still deliver 27-40 miles of pure battery operation for most of the days.

One of the mentioned applications should be selected. After the selection is made, the next logical step would be to undertake a more detailed design study for that particular vehicle, followed by a cost analysis and a prototype vehicle implementation.

Further efforts are also required to improve the fuel efficiency of current engine-generator sets and to reduce their emissions.

TABLE 19: SUMMARY OF RECOMMENDED DESIGNS FOR EACH SCENARIO

SCENARIO		w/o A.C.	w/ A.C.	Comments
RESIDENTIAL POSTAL Mail Del. Veh.	EV	(All)	Na-S Ni-Fe Ni-Zn	Increased battery life for the EVs w/o A.C.
	Hv	(None)	Pb-Ac Pb-Ac(GC)	
SMALL DELIVERY Mini Van	EV	Na-S	(None)	
	HV	Na-S Ni-Fe Ni-Zn Pb-Ac(GC)	Na-S Ni-Fe Ni-Zn Pb-Ac(GC)	w/o A.C. RX= 2.5-5 KW W/ A.C. RX= 6-8.5 KW
LONG DELIVERY Van	Hv	Na-S Ni-Fe Ni-Zn Pb-Ac(GC)	Na-S Ni-Fe Ni-Zn Pb-Ac(GC)	For 100 and (150) mi RX=4.5-7.5 (8-10.5)KW and if A.C. is desired RX=8.5-11 (12-14.5)KW
	EV	Na-S		Only if 100 mi range w/o A.C. is desired
CITY (60 mi) Automobile	EV	Na-S Ni-Fe Ni-Zn	Na-S * *	* Ni-Fe & Ni-Zn EVs w/A.C. are slightly over the battery target weight
	Hv	(None)	Ni-Fe Ni-Zn	
LARGE METROPOLIS Automobile	Hv	Na-S Ni-Fe Ni-Zn	Na-S Ni-Fe Ni-Zn	For 150 and (200) mi RX=7-9.5 (8.5-10.5)KW and if A.C. is desired RX=10.5-13 (12-14)KW
INTERCITY TRAVEL Automobile	Hv	Na-S Ni-Fe Ni-Zn	Na-S Ni-Fe Ni-Zn	For 480 mi range w/o A.C. RX=14-15KW w/ A.C. RX=17.5-18.5KW
LOCAL BUS	Hv	(All)	(All)	Optimal application, w/A.C. RX=42-46 KW w/o A.C. only 12-17KW
INTERCITY TRAVEL Bus	Hv	Na-S Ni-Fe Ni-Zn Pb-Ac(GC)	Na-S Ni-Fe Ni-Zn Pb-Ac(GC)	Questionable application w/o A.C. RX=130 KW

REFERENCES

1. "Hybrid Vehicle Assessment, Phase I, Petroleum Savings Analysis". DOE/CS-54209-14. Prepared for U.S. Department of Energy by Jet Propulsion Laboratory, March 1984
2. "Hybrid Vehicle Engineering Task" Final Report. Aerospace Report No. ATR-86(7143)-l. Prepared for Electric and Hybrid Propulsion Division, U.S. Department of Energy, by The Aerospace Corporation. May 1986
3. "Development and Demonstration of an Extended Range Electric Vehicle" Phase I Report. EPRI rp 2664-5. Prepared for Electric Power Research Institute by Chloride Limited EV Systems Division. March 1989
4. "Advanced Electric Vehicle Powertrain (ETX-1) Performance: Vehicle Testing" J.E. Fenton and P.B. Patil. Ford Motor Company. VIII International Electric Vehicle Symposium, Washington, DC. October 1986.
5. "The DOE ETV-1 Electric Test Vehicle Phase III- Final Report. Performance Testing and System Evaluation". DOE/CS/5 1294-01. Prepared for the U.S. Department of Energy by the Jet Propulsion Laboratory, December 1981.
6. "Test and Evaluation Report for the General Motors G-Van". Research Project 1136-27. Prepared for Electric Power Research Institute by Tennessee Valley Authority. June 1988.
7. "Demonstration of Aluminum-Air Fuel Cells in a Road Vehicle" D.W.Parish, et al. SAE 891690. August 1989
8. "The Development of Aluminum-Air Batteries for Electric Vehicles" E.J.Rudd. SAE 891660. August 1989
9. "Performance Testing and System Evaluation of the Soleq Evcort Electric Vehicle". DOE/ID--10232. Prepared for U.S. Department of Energy by EG&G Idaho, Inc. March 1989.
10. "Simulation Modeling of Automobile Comfort Cooling Requirements" D.W.Ruth. ASHRAE Journal, May 1975.
11. 1987 ASHRAE Handbook. Heating, Ventilating and Air Conditioning Systems and Applications. pp 24.7-28.8
12. "Gen-Pro". Gillete Mfg., Inc. Engine-Generator sets brochure.
13. "GenSet". Onan Corporation. Engine-Generator set brochures.
14. "NP Series, RV Generators". Generac Corporation. Engine-Generator sets brochure.
15. "Air Pollutant Emissions and Electric Vehicles". Research Report UCD-TRG-RR-89-l. Q-Wang, M.A.Deluchi, and DSperling. Transportation Research Group, University of California at Davis. May 1989.

16. "Electric and Hybrid Vehicles Program" 12th Annual Report to Congress for Fiscal Year 1988. DOE/CE-0247. U.S. Department of Energy. Washington, DC. February 1989
17. "The Hybrid Vehicle Revisited" R.A.Renner and L.G.O'Connell, VIII International Electric Vehicle Symposium, Washington DC. October 1986
18. "Two Decades of Development and Experience with Hybrids" V.Wouk. IX International Electric Vehicle Symposium, paper EVS88-033, Toronto, Ontario. November 1988.
19. SAE Handbook 1987. Volume 4. pp 28.01-28.06
20. "The Chrysler Electric TEVan" Electric Power Research Institute. Information sheet
21. "News from Uniq". Unique Mobility Inc. Fact sheet. November 1989.