Research on Comparison between Hybrid Electric Vehicles and Fuel Cell Vehicles

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1. Survey of HEVS and FCVSM

1.1 Potential Environmental Efficiency

In order to solve the emission pollution of autos, improve the urban air environment and balance the utilization of various forms of energy resources, thus forming new growth points of auto industry, the governments of many nations, famous auto manufacturers and scientific and research institutions around the world pay special attentions on the research and development of electric motor cars and their promotion and application. At present, electric vehicle has been becoming one of the important trends and "highlights" for the development of international auto industry. In recent years, due to the influence of accumulator technology and high performance of cell cost and other factors, the development progress of pure electric vehicle is on the decrease. By comparison, HEVS and FCVS had made a series of important breakthroughs, some of which have shown promising perspectives for industrial and market development. The development and application of HEVS and FCVS are becoming the main stream for the development of electric vehicle.

Due to the same reasons and especially to the urgent requirements for realizing the crossing development of China's auto industry, Chinese government has, from the strategic view of realizing sustainable development, been devoted to speeding up the development of electric vehicle projects. During the 9th Five-Year Plan, the State Ministry of Science and Technology has, on the basis of initial research and development, organized and implemented the significant science and technology industrial engineering project of electric vehicle, with currently obvious achievements obtained. In order to bring the social efficiency and environmental efficiency of electric vehicle projects into full play, the state will start a new cycle of research and development and industrialization of electric vehicle projects during the "10th Five-Year Plan" , and provide necessary supports and preferences for the development of HEVS and FCVS. Promotion of the development and application of HEVS and FCVS in consideration of the state situation of our country will bring forth great potentials of environmental efficiency.

(1) Development of HEVS and FCVS is an effective way to the treatment of urban air pollution

With sustained rapid economic development of our country, the current demand of cars has been on a rapid increase, and it has been predicted that China will become the largest auto market in the future. Experts has estimated that, by the end of 2000, the stock of cars in our country will be about 5 million and in the year 2010, the stock of cars will reach about 14 million, with annual increase of about 1.5 million. For the stock and demand increase of cars in 2000, 2005 and 2010 of our country, please refer to Table 1.

Table 1 2000～2010 Stock and Demand Increase in Our Country

Type of vehicle	Stock (10 thousand)			Demand (10 thousand)		
	2000	2005	2010	2000	2005	2010
Car	560～460	880～860	1430～1340	80～66	140～110	200～190
Bus	360～340	460～450	570～550	41～38	44～40	55～50
Truck	750～680	950～910	1170～1150	90～70	92～88	110～100
Total	1670～1480	2090～2240	3170～3080	211～174	276～238	360～340

By the year 2010, annual auto demand of our country is about 3.5 million, and such a large market will bring forth great commercial opportunities for enterprises. But at the same time, the rapid increase of car stock is sure to bring forth a series of environmental, energy and traffic problems. The current environmental problems are already pretty serious in our country, and state statistics have shown that air pollutants in such big cities as Beijing mainly come from autos. Table 2 shows the proportions of emission from motor vehicle among major air pollutants in Beijing, Shanghai and Guangzhou in 1998. Environment monitoring has proved the idea that major pollution sources of air environment in large and medium cities comes from the pollution of motor vehicle emission in China. According to the information recently published by the World Bank, Chine has the heaviest environmental pollution in the world, and among the twenty cities with the most serious air pollution across the world, ten are located in China.

Table 2 Proportions of Emission from Motor Vehicle among Urban Air Pollution

Emission / Cities	CO	HC	NO_X
Beijing	63.4%	73.5%	56.0%
Shanghai	86.0%	96.0%	56.0%
Guangzhou	88.8%		79.3%

Increasingly serious pollution problems have led to great economic losses and according to estimation, air pollution and water pollution have caused total loss of about USD 54 billion on national economy of our country each year, which amounts to 8% of GNP of our country in 1995. With the increase of car stock, the consumption of fuel oil will further increase by great extent, and correspondingly comes the rapid increase of emission pollutants. It is estimated that, by the end of 2000, the consumption of gasoline by vehicle will reach 55.26 million tons in our country with annual increase of 19.9% and consumption of diesel will reach 17.05 million tons with annual increase of 42.7%. By 2010, the vehicle stock is predicted at 2～3 times by comparison with the current quantity, and calculated on this basis (calculated by the current combustion efficiency), the annual consumption of fuel oil by vehicle will increase to more than one hundred million tons, which will bring forth great pressure on the development of national economy of our country. Foreign exchanges used for import of fuel oil will increase by great extent each year. Utilization of diversified forms of energy resources may reduce the consumption of raw oil by vehicle and reduce the pollution of air environment by motor vehicle, thus reducing the import of raw oil and bringing forth great environmental and indirect economic efficiencies conducive to the development of our national economy.

At the beginning of the 1990s, the US put forward the Plan on New Generation Vehicle (hereinafter refereed to as the PNGV Plan) for the main purpose of reducing reliance on import of oil from foreign countries and reduced the foreign trade deficits of the government by way of enhancing the fuel (combustion) efficiency of vehicle. At that time (in 1993), about 50% of oil was required for import in the US, and import of oil occupied half of the trade deficit of the US, which brought great threats on the national energy and economic safety. In this circumstance, the US government coordinated with the relevant departments and through careful research, determined the objectives of the Plan on New Generation Vehicle, please refer to Table 3.

Table 3. 2004 Objectives of Super Vehicle Norms under the "PNGV Plan"

	Base-line vehicle norms	Super vehicle norms
Reorganized quality	3200ib	Reduction by 40% on the basis of the base-line (1920ib)
Air dynamic factor	0.32 Cd	0.20 Cd
Friction resistance	0.008	0.005
Energy sources	Combustion engine	Fuel cell Hybrid energy
Fuel efficiency	26.6 mpg	Increased to 80 mpg (objective of the 1st phase) Increased to 100 mpg (objective of the 2nd phase)

Research for many years shows that, at present, major auto manufacturers in the world have basically reached common recognition. There are three ways to reach the above-mentioned PNGV objectives: fuel cell vehicle, hybrid energy vehicle and diesel engine injection (GDI).

If GDI technology is not considered (this text only compares HEVS and FCVS), HEVS and FCVS will be the dominant technology among the advanced technology vehicle applications in this century.

The technological core for auto manufacturers has changed from fuel engines to fuel cells and hybrid energy, which considered from the viewpoint of technology, is mainly due to the following three major features of HEVS and FCVS:

1) Low emission (the emission of FCVS may be "zero");
2) Flexibility of fuel oil (utilizing the function of diversified energy in adjustment of energy composition and full use of various energy);
3) High efficiency and high performance (energy consumption may be reduced by great extent and the performance of vehicle may be improved).

Table 4 shows the economy and emission levels of fuel from HEVS and FCVS (during the full life cycle of vehicle).

Table 4. The Economy and Emission Levels of Fuel for HEVS and FCVS (current)

Effective methods	Fuel economy	Emission level

		CO	CO_2	HC	NO_X
Base line（based on diesel engine）	100 （combustion efficiency of 15% ）	100%	100%	100%	100%
FCVS(fuel cell vehicle)	200%～300%	0	0	0	0
HEVS(hybrid energy vehicle)	200%	10%	50%	10%	10%
GDI(diesel engine injection)	150%～200%		60%		

The American Fortune magazine comments: fuel cells will get rid of the noisy piston engines with environmental pollution that drive cars, trucks and buses in the world, just like getting rid of the steam engines. Though time is needed for realizing this objective, the potential environmental efficiency brought forth by HEVS and FCVS is obvious. The promising perspectives arising from the development of HEVS and FCVS have roused fierce competition among major international auto manufacturers and various companies that hope to enter auto industry with some market shares by adopting new technology.

In recent years, the rapid development and commercialization steps of hybrid energy vehicle and fuel cell vehicle are striking throughout the world. With the active participation, rapid increase of input and technological advances of major international auto manufacturers and oil giants, the development of HEVS and FCVS has gone out of laboratories, begun to come to the commercial process, and entered a new development stage with challenges and opportunities. The president of Benz-Chrysler Corporation has the opinion that: "fuel cells are the future of auto industry" , the auto market shares of the world will be redistributed within ten years; new companies with "fuel cell technology" will enter and some old companies will be withdraw. Nearly all Japanese auto companies have launched their own hybrid energy vehicles. It is represented that Prius vehicle produced by Honda Company are warmly welcome by the market, with an emission level reaching the current strictest emission standards in California and a performance/price ratio having certain market competitiveness. Table 5 shows a comparison of various performances between HEVS and FCVS as environmental protection autos.

Table 5 Comparison of Various Performances of Environmental Protection Autos

Types of Environmental Protection Autos	Power sources	Utilization performance	Economy	Environmental impacts	Energy availability
Alternative fuel vehicle	Engine	The storage and safety of compressed gas and liquefied oil with some hidden dangers, fuel filling station construction	Traditional engine influenced and restricted by Carnot cycle and auto work conditions, with low combustion efficiency (generally no more than 20%)	Great reduction of pollutant emission	Use of methanol, ethanol, compressed gas and liquefied petro-gas, unable to get rid of un-renewable petro-chemical energy (exclusive ethanol)
Accumulator vehicle	Electric motor	Low specific energy ratio, long power	Higher combustion	No pollution (adopting	Adopting renewable energy, big use of water

		charging time and short continuous distance; large input required on infrastructure	efficiency than traditional vehicle, which is far lower than FCVS and HEVS	recycling energy as power), accumulator of secondary pollution, highest emission of non green house and green house air during the full life cycle	power resources
Hybrid energy vehicle	Engine and motor	Overcoming the shortcomings of accumulator vehicle in short distance per charge of power, complex technology and heavy weight	Requirements for accumulators reduced, high cost of vehicle and higher combustion efficiency	Big reduction of pollution emission, still with some pollution	Use of gasoline and other alternative fuel
Fuel cell vehicle	Motor	Problems of hydrogen making, storage and adding to be solved; long continuous distance	Higher cost, extreme high combustion efficiency (80% possible)	No emission pollution	Maximum use of renewable energy, and high flexibility in use of fuel

Therefore, super low emission and zero emission of HEVS and FCVS provide a new and effective way to eliminate the pollution of motor vehicle, and their development and promotion of use must bring forth gigantic potential environmental efficiency.

(2) Improving the utilization structure of energy in our country and bringing forth potential environmental efficiency

Based on analysis of the current energy structure of our country, the storage structure of energy is extremely unbalanced, with pretty low utilization rate and use efficiency of energy, therefore, the use of new technology is very promising. Consumption of coal exceeds 60% of total energy consumption and oil equals to 69% of energy consumption in transportation industry. Energy consumption is mainly focused on coal in our country. Whether or not coals may be changed into energy for use in transportation industry, that is, coals to be changed into energy available for use by HEVS and FCVS, it is an important issue to be considered in investigating the environmental efficiency of HEVS and FCVS. Tables 6-9 show the energy structure and energy production in our country.

Table 6 2000 Prediction on Energy Consumption Composition of Our Country

Energy composition	Electric power	Coal	Oil and natural gas
Percentage （%）	27%	60%	13%

Table 7 Energy Consumption Composition of Transportation Industry

Energy composition	Electric power	Coal	Oil
Percentage(%)	25%	6%	69%

Table 8　　2000 Demand of Primary Energy of Our Country

Energy categories	2000	
	Standard coal （100 million tons）	Energy composition （%）
Oil	2.17～2.23	15.5～15.9
Natural gas	0.32～0.40	2.3～2.9
Coal	10.21～10.07	72.9～71.9
Others	1.3	9.3
Total	14	100

Table 9　1991～1996 Energy Production Composition of Our Country

Year	Percentage among total energy production （%）			
	Coal	Raw oil	Natural gas	Water power
1991	74.1	19.2	2.0	4.7
1992	74.3	18.9	2.0	4.8
1993	74	18.7	2.0	5.3
1994	74.6	17.6	2.0	5.8
1995	75.5	16.7	1.8	6.0
1996	75.3	17.3	1.8	5.6

The economic growth of China (in the recent ten years) has reached 9%, and its annual energy consumption has increased by an average of 4.9% (in the recent twenty years). At this speed, the raw oil gap of China will reach about 100 million tons by the year 2010, the relative shortage or large import of oil energy will bring forth serious constraints and influences on he sustainable development of national economy of our country.

Since 1994, our country has become a net oil importer. With rapid economic development, annual oil demand is increasing by great extent, and oil production can not meet the demands for economic growth, with annual import of raw oil spending large amount of foreign exchanges. In this circumstance, one of the effective ways to preventing large increase of raw oil import and enhancing potential environmental efficiency is the promotion of the practical progress of HEVS and FCVS. The existing technological advance has proven the feasibility for changing coal energy into energy available for use by HEVS and FCVS, which, if developed by scale, will play an active role in improving the utilization structure of energy in our country. Table 10 shows 1996-1998 raw oil production of our country.

Table 10　1996～1998 Raw Oil Production of Our Country (10 thousand tons)

Year	1996	1997	1998
Production	14141	14322	16020

(3) Through the enhancement of combustion efficiency and the reduction of oil consumption, HEVS and FCVS may bring forth the potential of environmental efficiency.

According to prediction on oil use from 2000 to 2010 of our country, oil gap of our country will reach about 100 million tons by the year 2010, for details of which, please refer to

Table 11.

Table 11 Prediction on Demands of Major Oil Products in 2000 and 2010 of Our Country

Categories of oil products	1995 (ten thousand tons)		2000 demand prediction	2010 demand prediction
	Production	Consumption	GDP growth of 8%	GDP growth of 7%
Gasoline	2840.8	2905	3800～4000	5900～6200
Diesel	3684.3	4332	5700～6000	8800～9000
Aviation oil	359.9	422	690	1400
Kerosene	68.9	85	100	110
Lubricants	266.7	256	322	408
Commercial heavy oil	2002.5	2634	3000	3300
Total	9223.1	10634	13612～14112	19918～20418
Difference (based on 1995)	1410.9		4389～4989	10695～11195

Table 11 shows that, by the year 2005, total import of the above-mentioned oil products will be about 43.89～49.89 million tons, and by the year 2010, about 106.95～111.95 million tons; Statistics of 1996 shows that raw oil consumption is 173.00 million tons, while production is only 156.00 million tons with a gap of more than 10.00 million tons. Raw oil consumption of our country will be rapidly increased with the economic development, and according to conservative estimation of experts, by the year 2010, the gap of raw oil demands will reach about 100 million tons. By the year 2010, if reduction of raw oil consumption by vehicle through adoption of new technology enables import of raw oil maintain at 20～30 million tons, thus reducing import of oil by 70～80 million tons, great comprehensive efficiency will be achieved.

(4) Promoting substitution of oil by coal in our country is another effective way to bring forth potential environmental efficiency

China is a country with large coals, and its energy consumption is hard to avoid the track based on coals. In recent years, our country has started to reduce the proportion of coal consumption in total energy consumption, since coal consumption is in accompany with high pollution and low efficiency. However, if FCVS and HEVS are adopted for use of coal fuel, the contradiction of pollution and utilization may be alleviated. In case certain part of raw oil consumption in transportation industry by 2010 is replaced by coal fuel, it will be conducive to alleviation of the over-dependence of economic development on oil resources in our country. The substitution of coal for oil will bring forth gigantic potential environmental efficiency. Tables 12-13 show the coal consumption and the pollution thereof in our country.

Table 12 Percentage of Coal in Energy Consumption and Prediction in Our Country

	1995	2000	2010
Coal demands (100 million tons)	11	14	18
Percentage in primary energy (%)	85	69	60

Table 13 CO_2、SO_2、NO_X and Particulate Dust Emission Produced by Coal Combustion of Our Country（1995）

Name of pollutant	CO_2	SO_2	NO_X	Particulate dust
Pollutant emission（ten thousand tons）	3007	2370	800	Percentage in total emission -77%

Annual emission of CO_2 in our country reaches more than 30.07 million tons, 13.6% among total emission around the world, second only to the US. Similarly due to the factors of coal combustion, SO_2 content in Beijing City is five times the warning value stipulated by the World Health Organization.

Experts have predicted that, 2000～2010 energy demands of various industries around the world are mainly as the following:

1) Energy demands in industry and agriculture is on the decrease (coal resource consumption in this aspect in our country shall also be reduced gradually);
2) Energy demands in construction industry will be of no big change;
3) Energy demands in traffic and transportation industry and tertiary industry will be increased by great extent, and especially, the rapid development of auto industry after 2000 will bring forth increased demands on quality energy resources;
4) Energy demands of living will be of little change, while use of natural gas will be on great increase.

Therefore, we shall research on how to enhance the combustion efficiency of the energy consumption increased by great traffic and transportation industry and tertiary industry and reduce the emission levels of increased energy consumption, which is also our objective in the future. Experts predict that, enhancement of energy efficiency by every 1% in our country will bring forth intangible efficiency of about RMB 13 billion. By the year, if we can reach the objective value targeted for the 1st phase of the US PNGV Plan（80MPG）, annual raw oil consumption may be maintained at the level of the year 1996 based on calculation as per the car stock of the current year, which will bring forth good economic and environmental efficiency for our country. Even based on the currently achieved technological breakthrough relating to HEVS and FCVS, the development of HEVS and FCVS is of special significance for China with high enhancement on the flexibility of energy demands and fuel economy, since China is a country of large coal production and consumption and with serious pollution caused by motor vehicle.

According to analysis, adoption of HEVS and FCVS may reduce the percentage of pollutants, please refer to Table 14.

Table 14 Air Pollution by Use of HEVS and FCVS

Name of pollutant	TSP	CO	NO_X	SO_2
Daily average value in 1999 （μg/cubic meter）	364	29	140	80
Predicted falling percentage of FCVS	100			
Predicted falling percentage of HEVS	50%	90%	90%	50%

In case Beijing changes all its stock of more than 6000 buses and more than 4000 medium buses into FCVS, annual reduction of emission will be what listed in Table 15.

Table 15 Reduction of emissions

Emissions	Carbon greenhouse gas	NO_X	CO	RTHC
Reduction of emission in ton	110,000 tons	800 tons	75 tons	620 tons

In conclusion, whether in urgent need for improving the air environment of cities, or in practical demands for adjustment of energy utilization and enhancement of the utilization of energy, or as an important way to safeguard the energy safety in the future for our country, the speeding-up of the development and application of HEVS and FCVS in our country will bring forth gigantic potential environmental efficiency and social efficiency.

1.2 The Current Situation for Development of HEVS and FCVS

Major foreign auto manufacturers have made big breakthrough in the development of HEVS and FCVS in recent years with rapid advancement.

1.2.1 The Current Situation of the Development of FCVS in Foreign Countries

Table 16 shows the situation in the development and research and preparation of FCVS from 1993 to 1999 in Japan, America and European countries.

Table 16. The Situation in the Development and Research and Preparation of FCVS in Foreign Countries

Name of enterprise and year			Fuel cell system			Vehicle performance	
	Enterprise	Year	Fuel category	Power	Secondary cell	Vehicle model	Continuous mileage
North America	Ballard	1993	Compressed hydrogen	120Kw	None	Bus of 20 people	160 km
	Ballard	1997	Compressed hydrogen	260 kW	None	Bus of 60 people	400 km
	Ballard	1999	Compressed hydrogen	275 kW	None	Bus of 75 people	560 km
	Ford	1999	Compressed hydrogen	66Kwnet:205 kW		P2000	
	GMM	2000	Liquid hydrogen	55 kW	Hydro-nickel cell	5 people	400 km
	Daimler-Chrysler	1999	Liquid hydrogen	70 kW (Modified methanol)	None	NecarⅣ	
	Chrysler	1999	Modified gasoline				
Europe	Daimler-Chrysler	1994	Compressed hydrogen	50 kW (net)	None	Truck Necar1	130 km
	Daimler-Chrysler	1996	Compressed hydrogen	50 kW	None	Truck Necar2	250 km
	Daimler-Chrysler	1997	Modified methanol	50 kW	None	Necar3	400 km
	Daimler-Chrysler	1997	Compressed hydrogen	190 kW(net)	none	Bus Neb	250 km
	Reynolds	1998	Liquid hydrogen	30 kW	Hydro-nickel cell	Travel bus laguna	
	Opel	1998	Modified methanol	50 kW(motor)	Hydro-nickel cell	Mini truck Zafira	
Japan	Honda	1996	Occlusion alloy	20 kW	Lead-acid cell	RAV-4L	250km
	Honda	1997	Modified methanol	25 kW	Hydro-nickel cell	RAV-4L	500km
	Mazda	1997	Occlusion alloy	20 kW(50kW/1999)	Super capacitor (20Kw)	DEMIO	170km
	Nissan	1999	Modified methanol		Lithium ion cell	RUNESSA	
	Toyota	1999	Occlusion alloy	60 kW	Hydro-nickel cell	FCX-1	
	Toyota	1999	Modified methanol	60 kW	Hydro-nickel cell	FCX-2	
	Toyota	2000	Compressed hydrogen	60 kW	Hydro-nickel cell	FCX-3	
	Dafa	1999	Modified methanol	16Kw	Hydro-nickel cell	MOEV	300km

Table 17 shows the trends of development and research of FCVS of major international auto manufacturers from 1993 to 1999.

Table 17. The Trends of the Development of FCVS

	Manufacturer	1993	1994	1995	1996	1997	1998	1999年
Japan	Dafa							Publication of MOVE-FCVS
	Honda				Hydro-FCVS	Modified methanol FCVS	To be launched in 2003	Alliance with GM for joint development of FCVS
	Nissan					Modified methanol FC system, participation in development of clean vehicle	To be launched in 2003～2005	Modified methanol FCVS
	Toyota						To be launched in 2003	FCX-V1(hydrogen) and FCX-V2（methanol）FCVS
	Mazda	Hydro-fuel trial car				Hydro-DEMO-FCVS	Join in the alliance of Ford-Daimler	Modified methanol FCVS
	Mitsubishi						Development of FCVS jointly with Mitsubishi	MFCV published for launch in 2003
US	GM	1990 modified methanol vehicle					Modified methanol FCVS publication and launch in 2004	Joint development of clean vehicle with Honda and cooperation with Fuji Heavy Industry
	FORD		Successful development of hydro-fuel electric vehicle			Modified methanol FCVS(P2000 sample), joint development of FCVS with Daimler	To be launched in 2004	P2000 launched FC5 Vehicle
	D-Chrysler		Successful development of hydro-fuel cell			Gasoline fuel cell vehicle	Joint publication with Daimler	Fuel cell Jeep sample and hydro-fuel NECAR4 sample
Europe	Volkswagen					Modified methanol fuel cell vehicle	To introduce vehicle sample in 2000	
	D-Chrysler		Hydro-NECAR-1		Hydro-NECAR-2	Establishment of Ford-Ballard alliance for development of fl cell vehicle, modified methanol fuel cell NECAR3-NEBUS	To be launched in 2004 and consolidation with Chrysler	Joint venture with Shell Oil, NECAR4 sample, modified methanol fuel cell vehicle
	Opel						Zafira fuel cell vehicle (methanol) at Paris Auto Exhibition	Zafira fuel cell vehicle (pure hydrogen)
	BMW							

Table 18 shows the change of technological development of Daimler-Benz 5th generation fuel cell vehicle NECAR5.

Table18. FCEV Development and Manufacture by German Benz-Chrysler

	NECAR1	NECAR2	NECAR3	NECAR4	NECAR5
Year	1994	1996	1997	1999	2000
Development objectives	Experiments on mini size	Hydro-fuel prototype	Methanol fuel prototype		Modified methanol
Fuel cell	PEFC-50W Power density 167W/L	PEFC-50W Power density 167W/L	PEFC-50W（two groups）	PEFC（1 groups）	A group of 75Kw PEFC fuel cell（Ballard）
Fuel	Compressed hydrogen	Compressed hydrogen	methanol（40 litres）	Liquid hydrogen	Liquid hydrogen
Distance		250km	400km	450km	450km
Maximum continuous mileage		110km/h		145km/h	145km/h
Representative model	Used in large vehicle, fuel cell of large area, with only two drivers	Multiple use vehicle（MPV） members increased to 6	Benz grade A	Benz grade A	Benz grade A, 1st practical modified methanol FCEV vehicle
Vehicle mass			1750kg		1450kg
Recovery of starting energy	none	none	none	none	None

1.2.2 International Development Situation of HEVS

Hybrid energy vehicle may according to different working condition adopt different power sources or their combination to form hybrid electric system. In recent years, the development of hybrid energy vehicle has become increasingly mature, and Japanese Honda and Toyota have launched Prius and Insight hybrid energy vehicles respectively in 1997 and 1999. In addition to sales in domestic market, they have been sold to American and European markets. By far, more than 40000 Prius vehicle have been sold. Table 19 shows the development status of HEVS by major Japanese auto manufacturers.

Table 19. The Development Status of HEVS by Major Japanese Auto Manufacturers

Name of company	Combustion efficiency	Hybrid electric system and forms	Secondary cell	Emission
Lingmu (experimental)	39.0km/l	Pu3 (engine＋motor)	Lithium ion	CO2 emission of Prius equals to half of gasoline engine, emissions of CO, HC and NO_X are one tenth of traditional gasoline engines.
Dafa（Experimental）	37.0 km/l	MOVE EC-11Ⅱ（engine＋motor）	Hydro-nickel	
Toyota Insight（launched）	35.0 km/l	IMA (engine＋motor)	Hydro-nickel	
Fuji Heavy Industry（experimental）	33.0 km/l	SHPS (engine＋motor)	Hydro-nickel	
Mitsubishi（experimental）	31.5 km/l	GDI-HEV（engine＋motor）	Hydro-nickel	
Honda Prius（launched）	28.8 km/l	THS-THS-C（engine＋motor）	Lithium ion	

Nissan （experimental）	24.0 km/l	NEO （engine＋motor）	Hydro-nickel	

The combustion efficiencies of various hybrid energy vehicle in the above-mentioned table are different, and only the hybrid energy vehicle from Honda and Toyota are launched in the market, those from others are only in conception. Expert analysis shows that the technological features of Toyota Insight hybrid energy vehicle represent the highest technological level of current HEVS, with their main technical features as listed in Table 20:

Table 20. Technological Features of Toyota Insight Hybrid Energy Vehicle

Technological features	Main content
Unique HONDA-IMA hybrid electric system	The system adopts engines as main power and motor as supplementary power at the rate of 9：1 with maximum moment of 1：1.4. Adoption of the hybrid power makes up for the defects of bad start acceleration performance of traditional gasoline vehicle, bringing the role of low-speed large moment of motors into full play, thus INSIGHT vehicle is of good combustion efficiency and dynamics when running on urban roads and highways. Upon deceleration, motor also acts as engines, enabling energy to regenerate effectively and charging the cells.
Low weight and high combustion efficiency of engine and CVT technology	Adopting the lightest and highest combustion of engines in the world, the engines adopt 3 cylinders of 1 litre with diluted combustion VTEC and with air/fuel ratio of 24. Adoption of low friction technology may not only enhance the combustion efficiency but also enable recovery of starting energy to increase by great extent. Engines adopt light carbon-penetrating forged link, low tension piston, magnesium alloy oil sump, raisin inlets, thin-wall cylinder, engine case and other technology to alleviate the weight of the engine. Adoption of CVT may enhance the combustion efficiency and the moment at a high speed, thus increasing the dynamic performance of vehicle.
Equipped with absorptive and catalytic converter directed against NO_X	Diluted combustion renders relatively high emission of NO_X, thus , “INSIGHT ” adopts the specially designed NO_X absorptive and catalytic converter, which absorbs large emission of NO_X from diluted combustion. When combusting at the theoretical air/fuel ratio of working conditions, the reducing of HC and CO enables NO_X to reactivate as N_2 into the air. This kind of converter is not easy to be infected by fuel of high sulfur, which is widely applicable.
Adopting low-weight unit designing technology and enhancing combustion efficiency	“INSIGHT ” adopts light vehicle body of high renewable lead alloy with unit weight of only 820 kg, a reduction of 150 kg by comparison with CIVIC vehicle of basically the same sizes, since Toyota has adopted the totally new manufacturing process, making the vehicle body and frame with pressed and cast lead alloy, which is totally different from the traditional technology of lasting process with punched lead alloy plate. INSIGHT pressed and cast lasting is similar to Audi A8 technological process. The weight of INSIGHT vehicle body of lead alloy is reduced by about 47% by comparison with steel vehicle body.
Performance and designing of motor	Unique design of INSIGHT enables the design power of motor to reduce by great extent, which is 10kw, 1/3 that of Honda Prius, and enables the cell weight to reduce to 20 kg, 1/2 that of Prius. Compared with the system of other hybrid energy vehicle, the weight of Toyota IMA system is about 57%.
Safety designing	“INSIGHT ” adopts G control technology, enabling the unit weight to reduce but not damage the unit safety or reduce the unit crank or torque rigidity, and the unit crank and torque rigidity have been enhanced by 13% and 38% respectively. Toyota research has reported that: the clash testing has passed front clash at 55km/h, front

	offset clash at 64km/h, and side and rear clash at 50km/h, reaching the highest level of safety with equivalent grade of vehicle in the world. Furthermore, hood hinge and wiper pivot with absorption of impulsive force have also be adopted to alleviate damage and injury to pedestrians.
Reduction of wind resistance factor and enhancement of combustion efficiency	The wind resistance factor of INSIGHT is only 0.25, which is another effective way for Toyota to enhance combustion efficiency and reduce emission. In order to reduce the wind resistance factor, careful study and improvement have been conducted on the air dynamic features of the unit vehicle, including designing the bottom plate. In addition, the rolling resistance of the new tyres has been reduced by about 40%（compared with those of the same sizes), thus realizing high level of stability, low fuel consumption and high combustion efficiency.

Compared with Japan, the US has taken a relatively low tone in respect of HEVS, with smaller market promotion compared with Japanese companies, and by far, American auto manufacturers have not formally introduced HEVS products available for sales in the market, while major manufacturers have been keeping on research and development of HEVS. As far as the 2000 Precept hybrid energy vehicle of American GM is concerned, the wind resistance factor is 0.163 with five seats, the motor power is 35 kW（47 horse power）, the engine power is 40 kW（54 horse power）, and the diesel turbine engine has 3 cylinders of 1.3 litre with pressure-increasing co-axis, and combustion efficiency reaching 2.94 L/100km（34 km/l）.

During the 16th World Motor Vehicle Conference held in Beijing on October 12, 1999, American GM introduced a new hybrid energy vehicle, with the main performance indicators as listed in Table 21. According to the plan of GM, the new hybrid energy vehicle shall be launched in 2000, while there is no report in this respect up to now. The combustion efficiency indicator of the new type of vehicle has reached the objective of 80MPG as required by the PNGV Plan.

Table 21. The Main Parameters of GM Hybrid Energy Vehicle

	Hydro-nickel	CNGEV1	Serial EV1	Parallel EV1	Fuel cell EV1
Economy of fuel		60 miles/gallon	60 miles/gallon	80 miles/gallon	80 miles/gallon
Emission	Zero emission	1/10 ULEV	1/10 ULEV	TIERII	1/10 ULEV
Fuel	Electric power	Compressed natural gas	Reorganized cracked gasoline	Diesel	Methanol
Continuous travel distance	160 miles	＞400 miles	＞350 miles(electric driven 35 miles）	＞550 miles(electric driven 40 miles）	＞300 miles
Maximum speed	80 miles/h（limited）	80 miles/h（limited）	80 miles/h（limited）	80 miles/h（limited）	80 miles/h（limited）
Power Seats	137 horse power 2	72 horse power 2	137 horse power 4	219 horse power 4	137 horse power 4

Ford and Chrysler have also introduced Ford P2000 and Dodge Dauntless ESX2 hybrid energy vehicle.

Major European auto manufacturers have also taken initiatives to develop and investigate on hybrid energy vehicle, but with different ideas to focus mainly on buses. They think that the applications of HEVS are mainly focused on the public traffic. At present, there are already more than twenty hybrid electric buses running in Stewert and Wersyer in Germany.

German Volkswagen has begun to reassemble hybrid energy vehicle ever since 1990s and made some testing, and Bosch and Volkswagen have jointly developed a hybrid electric system, which has been used on the Golf hybrid energy vehicle.

The two models of VERT and HYMME hybrid energy vehicle developed by French Reynolds have accepted the 10,000Km test-running.

The spokesman of Audi said that the Duo hybrid energy vehicle produced by them has been leased in Germany with a prediction of 500 leased within four years and he also believed that the hybrid energy vehicle will become one of the best choices for people to develop a new generation of low pollution, high efficiency and energy-saving vehicle.

On the 16th World Motor Vehicle Conference, Citroen also introduced parallel LPG and electric hybrid vehicle (BERLINGO、DYNAVOLT). The concept vehicle is equipped with LPG engine of 2 cylinders and 4 strokes（500cc），138v cadmium-nickel accumulator and energy management system, designed mainly for city vehicle, with reduction of emission. The speed of this kind of vehicle may reach 95km at a continuous travel distance of 260 km（single electric driving mode of 80 km in city, urban electric driving and non-urban hybrid driving of 150 km, with CO_2 emission of 80g/km）.

Recently, new emission criteria and energy-saving requirements will be implemented in German auto industry, when a car with oil consumption per hundred kilometer exceeding 5 litres will not be permitted to run on the road, which enables people to base more hope on hybrid energy vehicle and fuel cell vehicle.

As one of the parameters based on which emission performances of various types of vehicle are compared, CO_2 emissions of various types of vehicle from fuel manufacturing to full life cycle of vehicle as compared with CO_2 emission of various types of vehicle with gasoline engines are listed in Table Diagram 1.

Diagram 1. CO_2 Emissions of Various Types of Vehicle from Fuel Manufacturing to Full Life Cycle

The black part in the diagram refers to CO_2 emission produced during the manufacturing of the fuel, and the white part refers to CO_2 emission of the whole process. If CO_2 discharged by fuel used by the vehicle with gasoline engine as power from the making of fuel to the running of the vehicle is calculated as 100%, it is obvious that the CO_2 emission of fuel cell vehicle is lower. Taking different fuel as the power of fuel cells will produce different CO_2. If fuel cell vehicle adopts natural gas to produce hydrogen as hydrogen sources for fuel cells, CO_2 emission is about 50% that from gasoline engine. If natural gas is taken as raw materials to produce methanol which is then used to produce hydrogen as the hydrogen sources for fuel cells, CO_2 emission is about 58% that of gasoline engine. When the black part duplicates the black part, it means that CO_2 emission is totally produced from the process of fuel making, while the process of use has not discharged any CO_2.

Taking hydrogen directly as fuel, water is produced after reaction, and taking hydrogen from modified methanol as fuel, the harmful substance discharged is of very little amount. Therefore, taking fuel cells as the energy for vehicle has played a very important role in the treatment of urban air environment.

1.2.3 The Development Trend of Clean Vehicle

Table 22 shows the trends for major countries in development and research on clean energy vehicle throughout the world by the year 1998.

Table 22. The Trends of Major Countries for Development and Research of Clean Energy Vehicle throughout the World

Name of country	Survey of research and development	Survey of introduction	Achievements in introduction
Canada	● Motor vehicle: Government aids in research on high performance of accumulators; Methanol vehicle： Test-running on public traffic bus and long-distance commercial vehicle has been completed; ● Fuel cell vehicle: Government and the state have jointly invested on Ballard Company for experimental research on fuel cell buses；	Natural gas vehicle Expense of fuel is lower than gasoline；	Methanol vehicle: ～200 （1996）； Natural gas vehicle: About 17200 （1996）； 112 fuel-station constructed；
US	Federal government and 3 major auto companies have jointly promoted the "NGVP"； Vehicle of 3 times of combustion efficiency have been jointly completed before the year 2003; ● Motor vehicle： GM started marketing hydro-nickel cell electric vehicle EV-1,S-10 in California and other states in Autumn of 1998; Ford marketed lead-acid cell electric vehicle in 1998 and prepared to sell hydro-nickel cell electric vehicle; Chrysler began to sell lead-acid cell electric vehicle EPIC and prepared to sell hydro-nickel cell electric vehicle; ● Hybrid energy vehicle： 3 major companies uniformly announced that hybrid energy vehicle will be marketed during 2001～2005; ● Natural gas vehicle： GM, Ford promoted natural gas vehicle into	Since the energy policy has been published, alternative fuel vehicle develops rapidly; Motor vehicle： American Electrical Company and American Post Company signed an agreement on purchase of 60 thousand EV vehicle Methanol vehicle： Focusing on parallel use of gasoline and methanol vehicle; Natural gas vehicle： Since 1960s, focusing on and promoting transportation vehicle;	3900 EV vehicle （1997）； 19000 methanol vehicle （1997）； 6200 ethanol vehicle （1997）； natural gas vehicle：（1997） CNG-82000； LNG-960； LPG-273000；

	large commercial vehicle； ● Fuel cell vehicle： GM, Ford modified methanol fuel cell vehicle published, aiming to marketing in 2004； Chrysler and Ford announced that in 2015, commercial modified gasoline vehicle will be realized,		
UK	● Motor vehicle： About ten years ago, leading the world trends in motor vehicle technology, but due to unfavorable government guidance and promotion, the vehicle in UK mainly rely on import;		Motor vehicle： About 24000（mainly used for goods distribution and transportation）; About 300 natural gas vehicle
Germany	● Motor vehicle： The largest power company in Germany-RWE set up a development and research institution of motor vehicle, and auto manufacturers and accumulator manufacturers jointly conduct development on electric vehicle; Hybrid energy vehicle： （diesel engine and motor）hybrid energy vehicle development and research; ● Methanol vehicle： Test-running supported by the government has been completed； ● Fuel cell vehicle： Daimler-Benz published NECAR2 in 1996 and modified methanol FCVS in 1997； Siemens planned to publish fuel cell vehicle in 1999; Volkswagen planned to publish fuel cell vehicle in 2000;	Motor vehicle： In 1999 purchased electric taxi； In 1995, 22000 electric vehicle ran, 49% among which were traffic vehicle and 35% are case trucks； German federal post, German telephone and RWE have purchased 10 electric vehicle respectively, German Telephone has also purchased hybrid energy vehicle.	Motor vehicle： 4500（1996）； Methanol vehicle： ～350（1996），17 fuel stations added; Natural gas vehicle： ～100（1996）；
France	Motor vehicle：	Motor vehicle： French EDF has a fleet of 500 motor vehicle.	Motor vehicle： About 3000（1996）； Natural gas vehicle： ～200（1996）
Italy		Motor vehicle： Small scale experiments on mini buses； Natural gas vehicle： Cheap transformation expenses, Favorable fuel expenses and tax；	Motor vehicle： About 800（1996）； Natural gas vehicle： ～290000（1996）
Finland			Natural gas vehicle：

			About 450； LPG vehicle： 0.6～0.7 million；
Swiss		Motor vehicle： Motor vehicle traffic will be implemented in travel places;	Motor vehicle： About 2050（1996）； Natural gas vehicle： 20

Table 23 Predicted Sales of Motor Vehicle in California, the US by Various Auto Manufacturers

Manufacturer	Predicted sales of motor vehicle
GM	Oriented at the year 2003, introduced "EV1and S-10" motor vehicle with hydro-nickel cells adopted in 1998;
FORD	Oriented at the year 2003, marketed Ranger truck with lead-acid accumulators in 1998, and Ranger trucks with hydro-nickel cell to be launched in the market;
Chrysler	In 1997, started to sell "ＥＰＩＣ" mini department vehicle, and "ＥＰＩＣ" mini department vehicle with hydro-nickel cells also started for sales;
Honda	300 "ＥＶ Plus" vehicle with hydro-nickel cells started to lease to general consumers in south California;
Toyota	Several hundreds of "RAV-4 ＥＶ" vehicle with hydro-nickel cells sold in the US from 1997;
Nissan	30 "Altra ＥＶ" vehicle with lithium ion cells sold in 1998, 90 were on test-running in 1999.

Table 24 Predicted Sales and Development of HEVS and FCVS in the US by Various Auto Manufacturers

Manufacturer	ＨＥＶ development trends	FCVS development trends
GM	Sales of "ＥＶ１" predicted in 2001.	Modified methanol hydro-fuel cell vehicle on test; Concept design completed in 1999; Production preparation completed of fuel cell before the year 2004; Cooperative development jointly with Delphi and Ballard.
FORD	Sales of "Ｐ２０００" hybrid energy vehicle with aluminum alloy body predicted in 2005, the weight of which to be reduced by 1000 ib on the basis of the weight of the prototype Taurus vehicle (with a weight of 3000 ib）.	Direct hydro-fuel cell vehicle under development and research; In 1996, established a joint venture with Daimler-Benz and Ballard for research and development of modified methanol hydro-fuel cell vehicle; Sales of 100000 fuel cell vehicle in North America predicted in 2005.
Chrysler	Sales of "Dodge Intepid ＥＳＸ２" hybrid energy vehicle of aluminum alloy body predicted in 2003.	Cooperation with other companies for development of modified gasoline fuel cell vehicle; Cooperation with ＧＭ, Delphi, Exxon, Arco for undertaking of medium modified gasoline fuel cell vehicle targeted in 2015.
Honda	"Ｊ－ＶＸ" hybrid energy vehicle introduced in 1998, sales of "insight" hybrid energy vehicle launched in 1999, and natural gas	In February of 1997, purchased fuel cells from Ballard; In 1999, introduced FCX-V1 pure hydro-fuel cell vehicle;

	launched in 1999, and natural gas hybrid energy vehicle "Civic" under development and research.	In 1999, introduced FCX-V2 modified methanol hydro-fuel cell vehicle.
Toyota	Sales of "Prius" hybrid energy vehicle launched in 1997.	In 1996, introduced hydro-absorption occlusion fuel cell vehicle "RAV 4L V"; and in 1997, introduced modified methanol hydro-fuel cell vehicle.
Nissan	"Stylish 6" hybrid energy vehicle introduced in 1998.	Fuel cells ordered from Ballard in March, 1997.

Major Japan, American and European auto manufacturers have basically stopped commercial research and development of pure electric vehicle, and the present principal objectives are directed at HEVS and FCVS, with different breakthroughs. Especially represented by Prius and Insight, the development of HEVS has indicated good industrial and market perspectives of development.

1.3 Issues to be Solved

Though the development of HEVS and FCVS is rapid in recent years, but compared with the practicality of conventional fuel vehicle, further breakthroughs must be achieved in HEVS and FCVS before gradual acceptance by users or the market.

(1) Development of special engine and adjustable-speed belt (CVT) is the key technology for the development of HEVS

In terms of HEVS, the main issue is how to design the hybrid electric system, thus enabling more advantages in the unit performance, and maximizing the structure and the parameters, especially focusing on the way to further reduce the cost of the hybrid electric system and rendering it with more market competitiveness. In addition, in terms of auto manufacturers of our country, the development of the special engines and adjustable-speed belt used by the hybrid energy vehicle is the key technology to be solved in the development of HEVS, and other technologies are relatively mature and easy to solve.

(2) The unit application technology and supplementary technology with FCVS system are the key factors constraining the development of FCVS

Many issues exist to be solved for FCVS. At first, the life of mini electric stack needs to be further investigated and tested. Secondly, the cost of fuel cell engines. With too high cost, no market can take shape. And due to high unit price as the result of high cost of its hydro-nickel cells, the pure electric vehicle can not be marketed, thus coming at a standstill. In addition, the technology in storage and making of hydrogen has not been solved. Although it is a good way to make hydrogen directly with gasoline or coal, much effort must be made to research on achievement of breakthroughs. Once practical use is possible, a network for supply of hydrogen should still be constructed. This infrastructure is a social engineering that can not be solved solely by auto manufacturers, and government supports and great amounts of investment are needed with full coordination by the petro-chemical industry. Based on considerations in technology and economy, much time is needed for industrial practices of FCVS.

(3) For both FCVS and HEVS, enhancement of combustion efficiency and reduction of emission are the two common issues to be encountered

Table 25 shows the issues to be solved for the achievement of 80MPG targeted by the American PNGV Plan, which will be similarly encountered when our country develops HEVS and FCVS, with more difficulties in the actual realization based on our relatively weak technology.

Table 25 Issues to be Solved for the Achievement of 80MPG Targeted by the "PNGV" Plan

Energy conversion technology	? 4SDI —Lean No_X Catalyst —EGR ? Fuel Cell
Hybrid electric model	Parallel hybrid electric system
Energy storage system	Hydro-nickel cell Lithium ion cell
Fuel category	Gasoline; Low-sulfur diesel（below 50PPM）； Fischer-Tropisch Fuel； Dimethy Ether；
Light material	Aluminum alloy composite BIW Composite BIW
Electrical and electronic technology	Inverter control technology； Motor； Super capacitor.

(4) Cost will be the important factor constraining the development of HEVS and FCVS.

Besides the support by further development of technology, production by scale will be an effective way to reduce the cost of HEVS and FCVS. In the contradiction between practical cost and the expansion of production scale, public participation, especially the strong promotion and supports of governments are also important measures for acceleration of reducing the cost of HEVS and FCVS.

1.4 Improvement of the Economy of Fuel

According to the preliminary research report on American "PNGV" Plan, the key technologies for realizing "the New Generation of Vehicle" may be classified as the following four points：

- Technology of diesel engine with internal injection;
- Hybrid energy vehicle （gasoline engine and motor）；
- New type of fuel cell technology；
- Technology of low unit weight (a very effective way to enhance the combustion

efficiency).

Except for the first categories, the above-mentioned key technologies have been recognized by major international auto manufacturers, therefore, China shall also conduct its research on the economy of fuel based on the above-mentioned points, for the aim to determining the research and development directions in the auto industry area for the coming ten years of our country.

Since 1994, China has become a net oil importer, and obviously, the development of our auto industry can not be take its base on the use of imported oil. Even the US, a super power, has pointed out in its "PNGV" Plan that the national system of relying on oil must be avoided. For the aim to improve the economy of fuel, the US, Japan and Europe have all, under the coordination of the government, promoted the various plans on improvement of fuel economy and reduction of emissions. The following is a brief description of various plans of the US, Japan and Europe.

1.4.1 American "PNGV" Plan——（Plan on the New Generation of Vehicle）

American "PNGV" Plan is actually the plan on science and technology development for the coming ten years of American auto industry, designated to enhance the combustion efficiency and reduce reliance on import of foreign oil, thus reducing foreign trade deficits. Auto industry is an important component of American economy and ground transportation occupies 1/4 energy demands of the US. In the year when the PNGV Plan was formulated（1993）, import of oil reached nearly 50% of the consumption of the US, about half of the trade deficit of the US. Adoption of the new generation of cars may not only reduce the oil consumption but also reduce the emission of harmful gas and CO_2, reduce the raw material consumption of unit vehicle, enhance the renewable percentage of materials, and reduce waste material and other waste, thus facilitating the improvement of environment.

"PNGV" marks the new development ideas of the government and auto industrial circle, and at present, though the price of gasoline is low in America, users should not be encouraged to use vehicle with high consumption fuel. In the circumstance of shortage of market pulling force, the government shall invest on support of technological research and development of high combustion efficiency fuel, and support entry into traditional areas for break-up of monopoly, and advocate innovation. In this circumstance, the "PNGV" Plan was formulated.

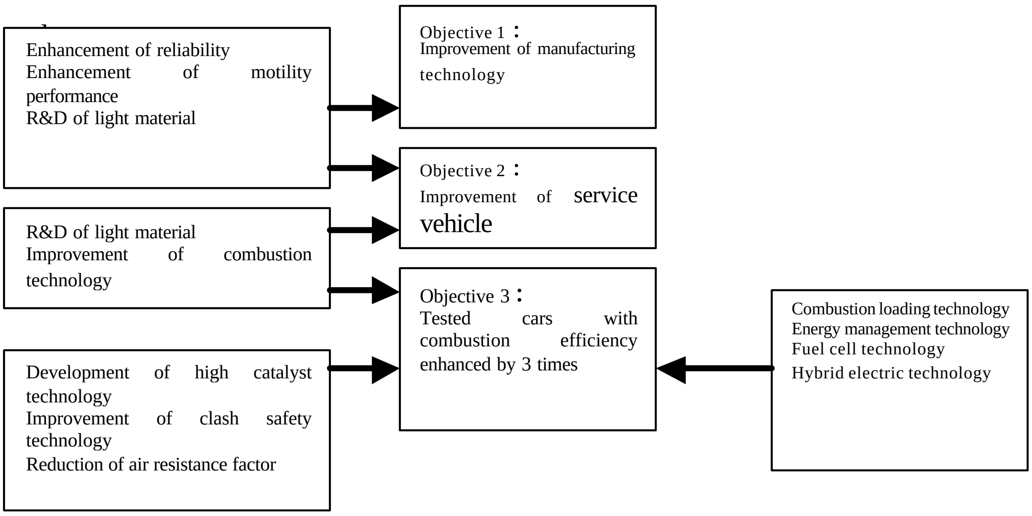
Through joint efforts of the scientific and technological institutions with the support of industrial circle and the government, the following three objectives have been formulated in the PNGV Plan for mutual support, mutual influence and mutual links:

- Improvement of the international competitiveness of auto manufacturing technology;
- Fast realization of the commercial and technological applications of the existing technological achievements;
- Enhancing the combustion efficiency of the service vehicle equivalent to

medium-size models（as per the American vehicle categories） by no less than three times.

The above-mentioned three objectives are interconnected, and Diagram 2 shows the key technology and the relationship between the objectives.

Diagram 2 Inter-relationships between the Objectives of the PNGV Plan



With the advance of technology, gradual improvement of combustion efficiency of the existing vehicles, reducing emission and enhancement of the safety have become the general trend. The average fuel efficiency of the three medium-sized cars of American 1994 Chrysler CONCORDE, Ford TAURUS, GM LUMINA is 26.6 miles/gallon gasoline, and the fuel efficiency of the new generation of medium-sized cars is 80 miles/gallon of gasoline (or alternative fuel equivalent to l14, 132BTUs heating unit in British system). Table 26 shows the parameters of the new generation cars with three times of fuel efficiency.

Table 26 Parameters of the New Generation Cars with 3 Times of Fuel Efficiency

Car features	Performance requirements
Acceleration performance	0-96.6 km/h acceleration within 12 seconds
Seats	6
Durance	160,000 km
Continuous mileage	610km（1994 federal laws and regulations）
Emission level	Meeting the requirements of No. Laws and regulations of 2004 EPA
Volume of Luggage compartment	0.48 cubic meter
Recovery rate	80%
Safety	Meeting the federal laws and regulation on vehicle
Operational stability and be comforts	Same with the current vehicle（of the same level）
Unit price and maintenance fees	Same with the current vehicle based on verification of fuel economy

Directed at the objective of 80MPG, the US has put forth 713 technological areas, 46 candidate technologies, with the content of technological research summarized as the following:

- Enhancement of combustion efficiency;
- Reduction of the unit weight;
- Realization of recovery of starting energy;
- Determination of the regeneration objectives of wastes.

1.4.2 European Plan on The Car of Tomorrow

Considering the American **PNGV Plan.** EU introduces the concept of the so-called plan on The Car of Tomorrow, which targets at the objective of "Enhancing the combustion efficiency by three times" of the **PNGV Plan,** and clearly puts forth the new concept vehicle with gasoline at "3 liters/100km". For the concept, research has been conducted on the following classifications according to different areas:

1. Electrochemical Energy Storage and Conversion Fuel Cell Systems：Stack Development, Fuel Processing and Storage
2. Energy Converter, Transmission and Control System for Hybrid Vehicles
3. Internal Combustion Engines: Fuelling, Combustion and Exhaust Gas After Treatment
4. Internal Combustion Engines: Clean Fuels and Fuelling Infrastructure
5. Vehicle light weighting, Drag Reduction, Safety and Telematics Systems
6. Demonstration, Measurements and Test, Comparative Assessment

The following are detailed descriptions on the research content relating to 2, 3, 4 and 5 of the above-mentioned classifications.

1.4.2.1 Fuel Cell Systems

1. Stack Development, Fuel Processing and Storage；
2. Development and Evaluation of an Integrated Methanol Reformer and Catalytic Gas Clean System for a SPFC Electric Vehicle (MERCATOX);
3. HYDRO-GEN: Second Generation PEM Fuel Cell Working with Hydrogen Stored at High Pressure for the Electric Vehicle (HYDROGEN);
4. Direct Methanol Fuel Cell: System Development and a Stack Construction (DMFC);
5. Second Generation SPFC: Development of Commercial Viable Stacks (COMMERCIALLY VIABLE SPFC);
6. Compact Methanol Reformer Test-Design, Construction and Operation of a 25kW Unit (COMPACT METHANOL REFORMER TEST);
7. Car Authothermal Process Reactor Initiative (CAPRI);
8. Development of a Full Size Electric Bus with Second generation Fuel Cell Stacks (FCBUS);

1.4.2.2 Energy Converters, Transmission and Control System for Hybrid Energy Vehicles

1. Magnetic Integrated Circuits for Industrial Switch and Sensor Applications (MAGIC);

2. SUPER-Transport-User Group, Automotive & Aerospace Systems (OMI-UG-TRANSPORT);
3. Multi-chip Module Automotive Digital Core for Electronics Control Unit (AUDICO);
4. Application Experiment (AE);
5. Internal Combustion Auxiliary Power Unit for Integration in Electrically Propelled Vehicles (ICAPU);
6. Research on New Technologies for Flywheel Electromechanical Storage Systems Development of Flywheel Motor Generator Unit for Peak Power Application in Electrically Propelled Vehicles (PEAKFLY);
7. New Power Conditioning System for Electrical Vehicles (CARTRONIC);
8. Low Weight Electric Bus with Multiple Energy Supply;

1.4.2.3 Internal Combustion Engines: Fuelling, Combustion and Exhaust Gas After Treatment

1. High Performance Simulation of Internal Combustion Engines (HPS-ICE)；
2. Embedded Filter Unit for Automotive Signal Conditioning (FILU)；
3. An Engine Management System Suited to Meet the Regulation Euro2000 by Means of an Enhanced Digital Core (CORE2000)；
4. Integrated Aftertreatment System of DI Diesels for Cars (DIDTREAT)；
5. Leanox Development for Lean Burn Cars and Diesel Trucks (LEANOXII)；
6. Reduction of NOX in Lean-Exhaust by Selective NOX-Recirculation (SNR-TECHNIQUE)；
7. Advanced DI Gasoline Engine (ADIGA)；
8. Integrated Electronic System for Dynamic Emission Control (ELSEC)；
9. DI Diesel Engine Noise/Vibration Control Technologies (DINOISE)；
10. Advanced Valve Control System (ADVACO)；
11. Mixture Preparation for Transient Operation；Experiments and Calculations (PREMIX)；
12. Diesel Engine Simulations Aiming to Reduce Emission Levels (DIESEL)；
13. Application of Advanced Chemistry and CFD to Pollutant Reduction in D Engines (PRIDE)；
14. Study and Modelling of Near Wall Turbulence in Internal Combustion Engines (NEAR WALL TURBULENCE MODELLING IN ICE)；
15. Optical Diagnostics for Industrial Applications in Combustion (ZOIAC)；

1.4.2.4 Internal Combustion Engines：Clean Fuels and Fuelling Infrastructure

1. New Catalytic System for Preserving the Octane Value During Hydro Desulfurization of FCC Gasoline (FCC DES)；
2. Use of Mesoporous Materials for Deep Catalytic Conversion of Heavy Oils by Residue Cracking and Hydrocracking；
3. Advanced Cobalt Based Catalyst for Fischer-Tropsch FT Synthesis；
4. Fuel and Lubricant Formulations for High Depolluted Engines (FLOVEV)；
5. Development of a Zeolite Based Catalyst for paraffin Alkylation in a Slurry Reactor (ZEOCATALK)；

6. Catalytic Partial Oxidation of Methane to Synthesis Gast (SYN-GAS)；
7. Compact, Energy-Efficient Reforming Technology with Reduced Environmental Impact；
8. Equipment for Fuel Cyclical Pretreatment of Special Application to Biofuels
9. Demonstration Project to Reduce the Urban Air Pollution Due to Transport by Using Natural Gas Fuel for Garbage Trucks。

The research of Europe is basically similar to American **PNGV Plan.**

1.4.3 Japan “Development Plan of High Efficiency Clean Energy Vehicle”

Considering the American **PNGV** Plan and European New Concept of “3 litres/100km”, Japanese Government has organized a development institution consisting of Japan Commercial and Industry and eight major auto manufacturers for promotion of the so-called “Development Plan of High Efficiency Clean Energy Vehicle’’ designated to alleviate the environmental loading and reduce fuel consumption. During the seven years from 1997 to 2003, a plan will implemented for promotion and development of a new vehicle (including fuel cell vehicle) combining hybrid electric and clean energy, with the following main content:

1. Enhancement of the fuel efficiency by more than 2 times that of the base vehicle;
2. Development and utilization of natural gas, hybrid fuel and other clean fuel;
3. Great reduction of the emission .

Institutions and enterprises participating in the “Development Plan of High Efficiency Clean Energy Vehicle” are mainly：

- Comprehensive Development Organization of New Energy Industrial Technology;
- Japan Automobile Research Institute—a corporate community;
- Wushiling;
- Nissan;
- Nissan Diesel;
- Riye Auto;
- Toyota Technological Institute;
- Mitsubishi Auto;
- Honda Auto;
- Mitsubishi Conglomerate Institute.

1.4.4 Common Features of the Three Different Plans

1. Establishing a development system integrating government, industry, academy and research, for joint promotion of the development of HEVS and FCVS;
2. Making use of the organizational and ordination strength of the government, enforcing innovation on energy efficiency and emission;
3. Based on academy and research, supporting the government in macro research on market, and assisting the government in establishment and perfection of the legal system;

4. With innovated ideas, setting up industrial alliance, for joint enhancement of the national manufacturing levels, enhancing the national economic competitiveness and promoting long-term sustainable development of the national economy;
5. Maintaining and increasing the market shares with high and new technology.

1.4.5 Comparison of the Researches Conducted by the US, Japan and Europe on Enhancement of the Fuel Economy

Table 27 Researches Conducted by the US, Japan and Europe on Enhancement of the Fuel Economy

Japan	US	Europe
Japan is in a leading position in terms of the technology of hybrid energy vehicle, Honda Prius and Toyota Insight have been launched in the market, and by far, sales of Prius are 40000. Fuel cell vehicle focuses on metal containers of hydrogen, liquid hydrogen and modified methanol are in progress and modified gasoline is supplementary.	Three major American companies are less advanced in research on hybrid energy vehicle than Japan, without any relevant products launched. In fuel cell vehicle: no clear attitude in modified methanol fuel cell vehicle, mainly focusing on modified gasoline, and due to unclear reasons, there are some shortcomings in modified gasoline at the present: ● The efficiency of modified gasoline if lower than hydrogen and modified methanol, with complex system; ● Modified gasoline can still not avoid the national system for reliance on oil; ● In the development in the future, the combustion efficiency of modified gasoline may not be suitable for the requirements of development; ● The system developed at present can not meet the performance requirements by vehicle in the future.	In general, Europe is less developed than the US and Japan. But, Daimler-Benz exceeds the US and Japan in research level of fuel cell vehicle, with the highest level in testing sample vehicle currently introduced. Levels of the products from the joint venture company with Ballard for manufacturing of fuel cells are as the following: ● In cost of products predicted with mass production in 2001 （annual production of 200000 sets） , unit components ： USD /20Kw, system components ： USD 30/Kw; ● The energy/volume of pure hydrogen fuel cell is: 1310 w/l, that of modified methanol:1230w/l； ● Specific power ： pure hydrogen of 1040w/l，modified hydrogen of 970w/l； ● Fuel cells Mark900 and Mark700 may be started at 45 degree and 25 degree below zero respectively ； ● 40 kW fuel cells for hybrid energy vehicle completed.

The purposes for the US to invest large capital on modified gasoline is a puzzle, and it is suggested that we shall conduct necessary researches on this issue before determining the development direction of the fuel cell technology.

Some European opinions also shows that: in the long run, pure hydrogen fuel cell vehicle shall be the mainstay, recent development shall focus on modified gasoline due to the infrastructure, and medium-term development shall be the combination of the hybrid status.

1.4.6 Development and Research of Bio-energy

Bio-energy is the main energy in the 21st century, which is renewable and recoverable. In order to cooperate and promote the development of the fuel cell vehicle, the US, Japan and Europe have all taken initiatives to develop bio-energy. Table 28 shows the preliminary prediction on the development of bio-fuel.

Table 28 Survey of Annual Plan on the Development of Bio-Fuel

Year	Bio-fuel	Development facing the market
1994－2000	Oxidant； Octane derivatives； Fuel extender Bio-diesel； Generation of power	General vehicle； Public bus； Granulate reduced by 25%
2000－2010	Ethanol Methanol Bio-diesel[2)] Electric power	Various traffic bus； Electric or hybrid energy vehicle （corresponding to fuel adopted）； Full promotion of using bio-fuel in traffic and transportation； Industrial production；
2010－2030	Ethanol Methanol Bio-diesel Electric power H_2；	Various traffic bus； Electric or hybrid energy vehicle （corresponding to fuel adopted）； Use of various large, medium and small vehicle； Fuel cell vehicle.

Enhancement of the fuel efficiency is a major short-term and medium-term (10～15 years） activity undertaken or to be undertaken, and Table 29 shows the research and development trends of the US, Japan and Europe during 1995～2010.

Table 29. Events and Future Trends of the US, Japan and Europe relating to Fuel Efficiency during 1995～2010（●determined，○predicted）

	Japan	The US	Europe
2000	●Enhancement by 8.5% based on 1990（gasoline vehicle） ●enhancement by 5% based on 1993（light gasoline and medium trucks）	○preferential tax for high fuel efficiency vehicle	●Germany and Denmark render preferential tax for high fuel efficiency vehicle ●introduction of 3Ｌ/100km Vehicle
2005	○enhancement by 15% based on 1995（gasoline vehicle）	☆application of introduced technology of 1st generation of PNGV cars（８０MPG）：HEVS	●enhancement of 25% based on 1995 as determined by German Auto Industrial Union ； ○The objective of European Auto Industrial Union is CO_2 emission of 155g/km ○The objective of ＥＣ Commission: CO_2 emission of

			120g/km
2010	○enhancement by 20% based on 1995（gasoline vehicle） ○enhancement by 15% based on 1995 （light gasoline and medium trucks） ☆Introduction of clean vehicle objectives：in 2010, 3.5 million （EV：20，HEV：180，CNG：100，LPG：22，methanol：22）	☆introduction of 2nd generation of PNGV objectives：100MPG+emission of 0(traffic vehicle)，50MPG （light trucks） Technological application: fuel cell vehicle, fuel gas turbine engines	

Reduction of the unit weight is a very important way to enhance the fuel efficiency, and the objective of the PNGV Plan is to reduce the weight by 40%， and make full use of the energy and raw material consumed by the weight reduced at 40% during production and processing, which is of great significance. Table 30 shows the objectives, trends and initiatives taken by the US, Japan and Europe in the development of low-weight aluminum alloy body.

Table 30. The Objectives, Trends and Initiatives Taken by the US, Japan and Europe in the Development of Low-weight Aluminum Alloy Body （●determined，○predicted）

	Japan	The US	Europe
Objective and demands	○fuel efficiency and emission standards； ●enhancement of mobility； ●weight increased in consideration of safety； ○policy for mini components；	●fuel efficiency and emission standards； ○enhancement of mobility； ○weight increased in consideration of safety; ○policy for mini components;	●fuel efficiency and emission standards； ○enhancement of mobility； ○weight increased in consideration of safety; ●policy for mini components;
Trends	○Rapid enhancement of fuel efficiency according to COP3； ○in 2010, enhanced by 20% based on 1995； ○vehicle tax as per emission volume changed as per fuel efficiency；	○efforts made to meet the relevant regulations of ＣＡＦＥ； ○targeted in 2004, developing “PNGV”vehicle at 80MPG； ○development of super light steel vehicle	○vehicle tax eliminated and adopting tax as per fuel efficiency; ○3L/100km vehicle targeted for mass production in 1999; ○in 2005, enhanced by 25% based on 1990.
Initiatives	3	2	1

1.4.7 Preliminary Suggestions for Improvement of Fuel Economy in Our Country

The above-mentioned descriptions show that enhancement of fuel economy by great extent is the mainstream for the development of international auto industry, and also one of the largest powers for the development of HEVS and FCVS. At present, the domestic auto profession has not formulated clear objectives and tasks for improvement of the fuel economy, and by considering the domestic development of HEVS and FCVS, accounts should be taken comprehensively on some of the following major issues required to be answered as soon as possible: 1） determining the recent objectives of fuel economy in our country, 2） determining the types of technology corresponding to the objectives of the fuel economy; 3） determining the development direction of the fuel types; 4） the way to improve the energy composition of our country.

On that basis, the government departments are suggested to adopt special actions as the necessary measures for promotion of improving the fuel economy, thus putting in more forces in development and application of HEVS and FCVS.

（1） Establishing standard law and regulation system suitable for fuel economy and emission indicators of our country;
（2） Considering the international trends, the current " fuel oil tax system" not formulated shall be changed into " tax based on efficiency"；
（3） Suggesting the state to set up several experimental cities for adopting " CAFE" system and implementing tax based on fuel efficiency, and for implementing " CAFE" measures in manufacturing industry.

2.Technical Methods for the Development of HEVS and FCVS and Comparison of Them

2.1 Technical Difficulties of HEVS and FCVS

Table 31. Comparison of Technical Difficulties of HEVS and FCVS

	FCVS	HEVS
Technical difficulties	● Research on FCVS； ■ Stack loading application technology； ■ Research on stack assisting system； ■ Fuel research（economy, safety, flexibility and emission performance）； ■ Catalyst； ● Research on hydro-sources； ■ Preparation of compressed hydrogen； ■ Preparation of liquid hydrogen； ■ Modification technology（gasoline, methanol and others）； ● Technology of vehicle hydrogen storage；	● Research on the running mode of vehicle； ■ Hybrid electric modes； ● Research on the control mode of hybrid energy； ● Research on the distribution mode of hybrid energy； ● Research on the distribution apparatus of hybrid energy； ■ Adjustable-speed belt（CVT）technology research； ● Research on key parts and components； ● Technology of light unit weight； ● New fuel engine technology（VVT-I technology）； ● Electrical and electronic technology(dynamic large power and supplementary electronics, control

	■ Pressure hydrogen bottle ; ■ Liquid hydrogen bottle ; ■ Hydrogen absorption occlusion alloy storage ; ■ Hydrogen storage with nanometre materials ; ● Technology for preparation of vehicle hydrogen ; ■ Direct hydrogen technology ; ■ Modified methanol technology ; ■ Direct methanol technology ; ■ Modified gasoline technology ;	management system) ; ● Accumulator technology ; ■ High specific energy, specific power cells ; ● Motor technology ; ■ Generation technology suitable for recovery of starting energy ; ● Technological research on catalyst converter ;

2.2 Feasible Plans on and Ways to the Development of HEVS and FCVS in the Future

At present, major auto manufacturers in the world seem to have reached the recognition that, compared with fuel cell vehicle, the development of other so-called transitional technologies may not be said to be totally at a standstill, but losing the strategic position ".

The challenges of HEVS and FCVS against traditional vehicles have already been deployed globally, and as targeted by the year 2004, the US, Japan and Europe will launch HEVS and FCVS in the market at 80MPG. Major auto manufacturers in the world have all completed the concept cars and many manufacturers have already completed the testing sample cars and development of commercial vehicle, which may be said has been prepared well and entered the stage of "production preparation".

Considering the international development situation of HEVS and FCVS, our country shall also set up the development system integrating government, industry, academy and research for the development and preparation of HEVS and FCVS vehicle, especially focusing on the mainstay of enterprises and realizing the ultimate objective of industrial development. In order to shorten the R&D circle and speed up the efforts on HEVS and FCVS to reach the status of " production preparation" , suitable development plans and ways should be selected for the development of HEVS and FCVS.

2.2.1 Background of technological introduction and joint ventures by major domestic auto manufacturers

At present, all major domestic car manufacturers have fully undertaken joint ventures, with detailed circumstances listed as the following:

Joint venture	Chinese party	Foreign enterprise	Name of products
No. 1 Auto—Volkswagen	No. 1 Auto	German Volkswagen	Jetta and Audi

Shanghai——Volks wagen	Shanghai Auto	German Volkswagen	Santana and B5
Shanghai —GM	Shanghai Auto	US GM	Buick
Tianjin —Honda	Tianjin Auto	Japan Honda	
Guangzhou —Toyota		Japan Toyota	Yage
Dongfeng —Citroen	No. 2 Auto	French Citroen	Fukang

In addition, although another five mini-auto manufacturers have not undertaken full joint ventures, their main products are Japanese products introduced; and the development of new products also mainly depends on foreign auto manufacturers, which are listed as the following:

Tianjin—Huali	（original products are introduced from Japanese Dafa Corporation since 1984）；
Harbin—Songhua jiang	（original products are introduced from Japanese Mitsubishi Corporation since 1987）；
Chongqing-Chang 'an	（original products are introduced from Japanese Lingmu Corporation since 1988）；
Jingdezhen-Chang he	（original products are introduced from Japanese Lingmu Corporation since 1988）；
Liuzhou—Liuwei	（original products are introduced from Japanese Mitsubishi Corporation since 1987）

Total production of the five manufacturers approached 500000 in 1999 with rapid increase, but with low level of technologies, which are suitable for use in medium and small cities of our country recently. However, in the long run, the five mini vehicle manufacturers are of initiatives to enter into the production team of cars, and limited by their own shortage of the technological capacities for development of cars, they must introduce new products for production of cars.

Considering the overall level of China's auto manufacturers, the fuel efficiency of the vehicle produced is low, with a emission level designated to reach the standard level of 94/12/EC in 2005 (equivalent to European No.2 Standard). And considering the technological level of the existing vehicle, the achievement of reaching European No.3 Standard of emission is hard to realize within five years solely with our own strength.

Our auto industry may progress in order: "transitional emission（reaching European No.1 Standard）——low emission（European No.2 Standard）——super low emission（European No.3 or 4 Standard） ——zero emission", which is a development path followed by foreign companies, losing the strategic initiatives and position at the rapid pace of economic globalization and integration. Therefore, learning from the results achieved in the foreign auto area with advanced technology, we shall adopt the "Frog-jumping techniques" for direct penetration into the areas of hydro-fuel cell vehicle or hybrid energy vehicle, thus reducing the cost for development and preparation of the transitional technology and sparing the R&D time, speeding up shortening the technological gap with foreign major auto manufacturers. We shall adopt the measures for "narrowing the gap" , which may be classified as strategic and technological.

2.2.2 Strategic Options to be Adopted by China Auto Industry（mainly car industry）

China has made a rapid progress in auto industry in the recent decades, while the key technology and equipment of major domestic auto manufacturers are all introduced from foreign countries, having not gotten rid of the development path of "reliance'. Even in the coming 5～10 years, we can not completely avoid the situation that "key technology depends on introduction and product development depends on foreign countries". Therefore, we shall learn from the experiences of the US, Japan and Europe in development, speed up establishing the tetrad hi-tech R&D system, make use of the guiding role of the government, set up China's "PNGV" Plan, or named as CNGV—"China New Generation of Vehicle Plan", and backed up by the huge potential market of China, promote the development of HEVS and FCVS of our country. Details of the strategic options include:

(1) Focusing on hi-tech-pulling strategy with supplementary enforcement of laws and regulations and standard system;

Considering the current situation of energy and environment protection in China, the auto industry shall apply hi-tech for the development of products in the future, thus meeting the requirements of the strategy of sustainable development.

Promoted by hi-tech, the introduction of the new generation of cars will bring forth fundamental innovation with traditional vehicle in materials, fuel, and the "four processes", thus rendering material changes of industrial structure, further requiring the following up and response by such industries as "iron and steel, non-ferrous metals, chemicals, energy, electrical and electronics". The current gaps shall be overall narrowed, most importantly, narrowing the gap of development space for the coming 10～20 years. While adopting the pulling force of hi-tech, the auto industry, fuel and other relevant industries should be comprehensively regulated by laws, with corresponding policies formulated and standard systems perfected to facilitate the health development of HEVS and FCVS, such as adopting laws equivalent to American "CAFE" laws for the enforcement of average fuel economy with auto manufacturers, and granting certain tax and policy incentives for the promotion of the R&D and production of fuel available for new HEVS and FCVS.

Target values of the fuel economy and other indicators shall be investigated and formulated for the "China New Generation of Cars", the initiatives of auto manufacturers shall be motivated, and perfection of laws and regulations enables auto manufacturers to put in more capital and efforts on the development of HEVS and FCVS, thus speeding up the development progress of HEVS and FCVS.

（2）Formulating China's "New Generation of Vehicle" Plan, and focusing on speeding up the industrialization of HEVS and FCVS

In the situation of global integration of auto industry, major international auto manufacturers have adopted alliance and cooperative development for implementation of the "win-win" strategy. International cooperation should also be strengthened in China's auto industry, and innovative ideas should be adopted to guide and develop the projects of HEVS and FCVS for quick achievement of the designated objectives. At domestic level, the development path of " integration, unity and self-improvement' should be stuck to, and at international level, the win-win mode for "external development' should be kept. Through domestic cooperation between "government, industry, academy and research" , the capability and strength of self development and innovation should be motivated, and the efficiency of limited capital shall be maximized, thus strengthening our international competitiveness and our position in international cooperation.

Many transnational auto groups want to enter into China market, and many ways are available. By comparison, alliance with Chinese enterprises is the best one, only by which can reciprocal social efficiency and economic efficiency be obtained.

(3) Realizing self development of HEVS and FCVS, and going out of the shadow of "technological introduction" and "joint design"

Joint domestic and international efforts for development of HEVS and FCVS are good ways to solve the long-standing domestic problem of "small production scale, too weak independent development capacity and backward technology". Globalization of auto industry has started the "global optimal purchase of spare parts and component" and the new mode of "alliance" is different from the current "technological introduction " and " " joint design " of brands. Initially, "key spare parts and components or systems " come from global purchase or some neutral providers of international partners (in fact, major international auto manufacturers increasingly depend on the products of neutral providers) . Take for example, the fuel cells of Ballard have been used by major American, Japanese and European auto manufacturers, and even some alliances have been reached between them. By this way, the situation of lasting dependence on others may be avoided, thus realizing the real independent brands. At present, most of the competitive enterprises of our auto industry are joint ventures with technological and product introduction, with most products and technology falling in the hands of foreign parties, and domestic competitive auto brands are all actually introduced, without our own brands. All those are the kernel reasons leading to the long lasting vicious cycle of our auto industry with "introduction--being backward—repeated introduction—repeated backwardness". The R&D of high and new technology enables China to adopt the "frog-jumping" mode, thus avoiding the vicious cycle, narrowing the gap with advanced international technology, and strengthening our self-confidence and competitiveness.

(4) International cooperation facilitates win-win of talent introduction and technological introduction

Through international cooperation and cooperation or alliance with companies possessing key technology of HEVS and FCVS, we can adopt their most advanced technology for development of our products and enhancing the international competitiveness of our products (such as cooperation with Ballard for adoption of their fuel cell technology). At domestic level, we shall concentrate all efforts in talents, finance and materials for systematic integration and for development of certain key technologies that are hard to obtain through cooperation. Whatever are our shortcomings or unavailable at present may be obtained through optimal global purchase. Especially in terms of key talents, we shall offer high salaries for global employment, and their participation may bring forth new ideas, new technology and new concepts, which will facilitate overall enhancement of the technological levels of domestic talents.

1.2.3 Technological Strategies.

China is currently in the preliminary stage of automation, while the air pollution of big cities has been serious, with increasingly serious traffic problems. Furthermore, the petrochemical energy of China is not sufficient, and the way out for China's auto industry is to seek for high efficiency and clean alternative energy as well as environment friendly advanced auto technology, thus fuel cell vehicle technology is one of the 1st options. Considering the current situation of China. There are many plans on how to select the hydro-fuel as the fuel of fuel cell vehicle. But fuel cell vehicle that adopts pure hydrogen as its fuel can not form industrial development within the coming ten years mainly due to the following reasons:

- Preparation of hydrogen needs the support of certain infrastructure industry, the construction of which needs tome and capital;
- The transportation of hydrogen (safety and cost) requires perfect network and facilities;
- The bottleneck of construction of hydrogen stations (construction and investment of infrastructure and problems relating to safety).

It is pretty feasible to adopt methanol or modified methanol to facilitate the transitional development of fuel cell vehicle, and adoption of modified methanol is of the following benefits:

- Making methanol from coal may effectively change the energy composition of our country, and enhance the utilization of coal energy;
- The transportation of methanol is of low cost and good safety compared with pure hydrogen;
- Modification of methanol is easier than modification of gasoline in technology;
- The filling station of methanol may be available with transformation of the current fuel station, with less investment on infrastructure;
- The current production of methanol is larger than demand in our country, with better development base.

Since methanol is some poisonous, therefore whether to adopt modified ethanol or gasoline should be determined after careful and adequate research. Considering the fuel efficiency and utilization and production cost, as well as the energy status of our country, methanol is more suitable than gasoline. Once the poison of methanol has been solved, the safety of methanol may be easily guaranteed.

Therefore, modified methanol is ideal hydro-sources for fuel cell vehicle in the transitional period.

The technological development plan on hybrid energy vehicle mainly covers the following three modes: serial, parallel and hybrid. Different auto manufacturers have developed their own different technological path of products, and there have been some analysis and comparison relating to the three technological plans at home and abroad. In recent years, on the basis of development practices, the agreed opinion is that the serial technological path is conducive to the enhancement of the fuel economy, that hybrid technological path is more conducive to the improvement of vehicle emission, while the parallel technological path is not suitable for the development of HEVS in the future, among which the hybrid mode is of the highest difficulty in the technology of HEVS. Viewed from domestic research and development of HEVS, different technological paths are concurrently tested on the development of HEVS, and as the selection of technological direction for the development of HEVS in the future, it is currently hard to decide which one should be clearly adopted. Suggestions for the possible technological path are:

- In the HEVS development project guided and implemented by the government, domestic efforts should be concentrated with the development of hybrid HEVS as the objective, thus making big breakthrough in key technology and promoting the industrialization of R&D results;
- Based on enterprise, in the project of independent development or cooperative research and development of HEVS, we shall abide by the fuel economy and emission indicators available with HEVS in short term or medium term, guide and support enterprises to select the technological path independently, and make use of diversified efforts to narrow the domestic development cycle for the industrialization of HEVS.

2.3 Recently (within five years) Expected Development Progress and Performance Available

At present, domestic research and development of HEVS and FCVS has been started, all of which are of free will and diversified without any scale or integral power formed. The representative work involved includes: No. 1 Auto has tested on hybrid electric mode with Hongqi Cars, No. 2 Auto has made research and development on hybrid power with buses, some mini-vehicle manufacturers are very active in this work, some of which even have authorized colleges and universities and research institutions to conduct experimental research on the hybrid energy vehicle, such as Harbin Plane has entrusted Harbin University of Technological Engineering with research on hybrid energy vehicle. At the same time, almost all the higher education institutions and scientific and technological institutions with auto specialties have conducted researches on this issue.

Based on the domestic development status, the recent (in five years) development progress of HEVS and FCVS mainly depends on the following factors:

(1)Attitudes of domestic auto manufacturers

In terms of the technological and economic strength, the existing domestic auto manufacturers (exclusive of joint ventures) is not capable of the development and research of HEVS and FCVS （while scientific and technological work of development nature will continue）, and even some have not fully recognized the impact brought forth by HEVS and FCVS. Confused attitudes are mainly due to the insufficient strength in technological development and R&D capital.

(2)Higher education institutions and research institutions are very active in the development of HEVS and FCVS, while they can not lead the commercialization progress of HEVS and FCVS;

Some of our higher education institutions and research institutions are of certain research levels in part of the applications of HEVS and FCVS, with larger impact and influence, while the gap in commercialization and industrialization with the currently a dvanced levels of the world is much big. Especially, the key technologies have not been actively coordinated and supported by auto manufacturers, which in short time (5～8 years) can not reach the level for commercial tests with assembled vehicle.

(3) Some domestic enterprises declare that they have possessed the key technologies for production of HEVS and FCVS, which in most cases may be regarded as a kind of propagation for advertising effects;

The key technologies for the production of HEVS and FCVS necessitate large amount of R&D capital input and technological supports, which is not acceptable for ordinary enterprises, and what they called key technologies is not sufficient to support the research and preparation of HEVS and FCVS samples, being a far cry from the commercial production.

(4) Research and preparation of the concept HEVS and FCVS that may be completed recently （3～5 years）;

Considering the key technologies mastered domestically, the research and preparation of concept cars as well as the research and development and testing of medium or large sample buses may be completed within 3～5 years.

(5) It is less possible for foreign parties to our joint venture to arrange for domestic production of HEVS and FCVS within five years;

In addition to mastering The key technologies of HEVS and FCVS, the development of HEVS and FCVS requires the corresponding transformation and innovation of traditional auto manufacturing process, material, and model designing technologies. No enterprise in our country is of this capacity, including joint ventures. The infrastructure of our country within five years is not capable of supporting the running of FCVS vehicle.

(6) If the government organizes and sets up a New Generation of Vehicle Organization for the development of vehicle, the research and preparation of the concept vehicle may be completed within five years.

2.4 Recent and Long-term Development Perspectives of HEVS and FCVS

2.4.1 Recent and Long-term Development Perspectives of HEVS and FCVS by Foreign Countries

Japanese Honda and Toyota have launched HEVS products in the market, and by the year 2004 or even earlier, the three American auto companies may launch hybrid energy vehicle products in the international markets. Recently, the perspe ctives for industrialization and commercialization of HEV vehicles are very promising.

FCVS vehicle will be launched even earlier that the year 2004, while the promotion and application may be limited by the infrastructure, and it is predicted that they will be run firstly on the public traffic lines in big cities, then progressing to cars, the lagging time is predicted within 3～5 years.

2.4.2 Recent and Long-term Domestic Development Perspectives of HEVS and FCVS

The current technologies of our country is lagging after foreign countries for more than ten years, and within 5-10 years, HEVS will create some market, while it is predicted that FCVS may begin to enter the market ten years later.

2.5 Qualitative Analysis and Evaluation Comparison of HEVS and FCVS

At present, we shall take development of hybrid energy vehicle as the short-term and medium-term objectives and the long-term development objective will be targeted at fuel cell vehicle.

The fuel economy and emission of HEVS and FCVS corresponding to the short-term and medium-term objectives may be suitable for the standard requirements of the laws and regulation of our country as well as the advanced countries of the world, and the fuel cell vehicle may be suitable for the various requirements of medium-term and long-term fuel economy and emission.

But from the technological point of view, HEVS and FCVS are different in various aspects. The difficulties of fuel cell vehicle are larger than hybrid energy vehicle. The perfection of vehicle storage of hydrogen, modification and stacking technologies with fuel cell vehicle depends on the pace for commercialization progress of FCVS.

Considering the current technological capacity of our country, it is difficult to develop CVT, gasoline engine and diesel designated for hybrid energy vehicle (the development technologies of engines with hybrid energy vehicle are simpler than those of traditional vehicle).

The time when HEVS and FCVS are put into use depends on the following points:

- The perfection of the infrastructure;
- Vehicle fuel cell system;
- Performance and cost of the fuel cell vehicle;
- The acceptance of customers or the market;
- Whether suitable for the requirements of the relevant laws and regulation and standards of our country.

According to the currently conservative prediction, by the year 2020, total 25 million fuel cell vehicle will be used (1.8 of the vehicle stock throughout the world of the same year), and 1.78 million will be used in our country as calculated on the basis of the vehicle stock of our country of the same year.

Therefore, during thirty years from 2000 to 2030, the fuel cell vehicle takes only a small part in total vehicle of our country and throughout the world, other market shares are hybrid energy vehicle and traditional vehicle. Optimistic prediction shows that the stock of hybrid energy vehicle will exceed 30% at least, and that of our country shall be 30 million with total amount of 420 million throughout the world.

Conclusion: During the 10^{th} Five-Year Plan, the industrialization of hybrid energy vehicle will be one of the targets, investment should be strengthened on fuel cell and technological storage should be kept. The infrastructure should be perfected before the development of FCVS.

3.Infrastructure Required for Operation of HEVS and FCVS

The infrastructure required for the running of HEVS may take full use of the current infrastructure, and the infrastructure required for running of FCVS shall be determined in consideration of the types of fuel cells:

The mode with gasoline and modified methanol may use the existing infrastructure

- Modified gasoline fuel cell vehicle may use the existing infrastructure;
- The mode with modified methanol may use existing infrastructure or use it after some transformation;
- Daimler-Benz has the opinion that: the long term objectives for commercial production of fuel cell vehicle is to replace hydrogen with liquid methanol, which may be placed in the case as gasoline filled by ordinary fuel stations.

Gigantic investment must be put in the construction of the infrastructure for liquid hydrogen fuel or compressed hydrogen fuel.

4. Appraisal on Expense Input Required for Operation of HEVS and FCVS

Compared with FCVS, the technology of HEVS is relatively mature, with less difficulty. HEVS has been commercialized in Japan, with more than 40000 sold. Relatively speaking, FCVS is at the medium stage of research and development, some key technologies of which are available with resolutions, but the issue of cost is still the largest obstacle, thus a long way to go before their commercialization. The input on science and research is totally different from investment on industrialization, the former being much less than the latter. The production of HEVS may make use of the original vehicle assembly lines, only with electric driving system and electronic component assembly line added. While in terms of FCVS, except for the vehicle body, the assembly line outside the chassis platform should be transformed or newly built, with large amount of investment required. In terms of infrastructure, more problems exist with much more investment required. Special hydrogen-filling stations and network are required to be built with pretty large investment required.

The following expenses estimation is based on large or medium fuel cell buses as the reference models, while cars are taken as the reference model for expenses estimation of hybrid energy vehicle, one hydrogen-filling station or methanol station is added for reference with infrastructure investment.

4.1 Research and Development Input

(1) HEVS Research and Development Input

No.	Content	Investment
1	Designing research on unit car plan	4 million
2 3	Research and trial making of key technology and components Development and preparation of unit car and production of sample	16 million 15 million
4	Expenses for unit testing and test-running (10 cars)	10 million
TOTAL		45 million

(2) FCVS Research and Development Input

No.	Content	Investment
1	Research on FC improvement and cost reduction	30 million
2	Research and preparation of hydrogen supply system	5 million
3 4	FC with supplementary electronic and control system and unit control Research and preparation of ethanol reformer	10 million 8 million
5	Research and preparation of hydrogen storage technology and system	10 million
6	Development and preparation of unit car and production of sample (10cars)	20 million
7	Expenses for unit testing and test-running	10 million
Total		93 million

(3) Research on laws and regulations of standard system and incentive policies
5 million

4.2 Industrialized Investment

The establishment of production line shall make use of the existing buildings and available equipment of the auto plant, requiring special equipment and testing instruments and meters added only, and it is also necessary to cultivate technical talents and high caliber workers.

HEVS Industrialized Investment

1	Design of production line	5 million
2	Electric-driving and electronic component workshop	30 million
3	Unit assembly workshop （not newly built）	100 million （annual production of 10 million cars）
4	Personnel training	10 million
5	Development of products models （exclusive of body）	35 million
6	Current capital （200 cars）	50 million

Investment on FCVS added

1	Million	10 million
2	Fuel cell engine workshop	200 million
3	Hydrogen bottle or methanol reformer workshop	100 million
4	Turnover capital （FC as per 5000KW, 50 medium buses ）	60 million
5	Development of tools and models	80 million

4.3 Infrastructure Investment

Gas or oil filling for hybrid energy vehicle needs no additional basic facilities, which may be run with the existing fuel stations （gas stations） and network or a little transformation is proper.

Fuel cell vehicle needs construction of hydrogen supply stations and initial network, hydrogen manufacturers shall be built and safe transportation shall be considered.

At present, RMB 5-10 million is needed for construction of a hydrogen filling station in our country. The plan to be adopted for hydrogen making, storage and transportation, or for making hydrogen on the vehicle through methanol reforming is of great influence on the investment of the hydrogen filling station, and the key is the price and supplementary input of hydrogen filling facilities （or methanol filling） .

- Station facility construction（power, communication and water） 3～5 million
- Hydrogen filling facilities 2～3 million
- Safety facilities（alarming, distinguishing and pollution prevention） 1～2million

The investment on the construction of hydrogen plants is very large, and the existing plants may be used for technological transformation. At the initial stage, the existing hydro-sources may be used, such as industrial by-products, etc., and secondary investment may be made when the FCVS develops to certain amount. **4.4 Economic Influence** Alleviating the influence on the national safety;Reducing the aide effects on economic development;Conducive to the adjustment of energy composition;Conducive to the environment; andHi-tech industry brings forth the development of auto and the relevant industries.

5. Prediction of the Development Cycles of HEVS and FCVS

5.1 R&D Cycle During the 8th Five-Year Plan, China had arranged the research and preparation of electric vehicle and the development of key technologies as a national brainstorm project of science and technology, and during the 9th Five-Year Plan, the Ministry of Science and Technology arranged them as a key scientific and technological industrial project. At present, many pure electric cars and low-weight buses have been developed and prepared. Research and preparation have been focused on fuel cell vehicle, and it is predicted that a medium-sized fuel cell bus and two medium-sized serial hybrid electric buses may be produced on trial recently. In the recent ten years, the state has accumulated investment of 500-600 million on the research and preparation of cell and electric vehicle, with many high level research results achieved, and at the same time, cooperation and many technological exchanges have been conducted with foreign countries. The above-mentioned research and development have laid a good foundation for the research and development and industrialization of HEVS and FCVS.Based on the current domestic research and development strength, and by learning from foreign experiences, it is predicted that in terms of the research and development cycle of HEVS, the concept vehicle may be developed within 2-3 years, and that after a year of testing and improvement, trial sample cars may be completed, then a small batch of trial production and full demonstration running may be conducted within the coming two years. At the same time, initial industrialization may be carried out. Five years are predicted for completing the whole research and development cycle, which will lay a good foundation for mass production. In terms of the development of FCVS, three years are needed for completing the research and preparation of fuel cells and unit vehicle, in another 1-2 years, researches on improvement and reduction of cost will be conducted. Research and preparation of concept cars and large and medium-sized practical buses will be completed in five years, then another three years are needed for trial use and reasonable solution of the cost of the fuel cell vehicle, such as proper price, acceptance by users, then begins the commercial stage. If there is no breakthrough in the key technology of hydrogen making and storage, as well as reducing the cost, the cost will be relatively too high, with the development cycle to be extended correspondingly. What deserves mention is that, the above-mentioned estimation is just a preliminary judgement based on the development situation of HEVS and FCVS in foreign countries, the research and development basis in our won country, the technological maturity of the two modes, as well as the current cost available and other factors. With the advancement of technology, the research and development cycle of HEVS and FCVS will also change accordingly.

5.2 Life Cycle of HEVS and FCVS

(1) Some experts hold the opinion that HEVS is just a long-term transitional plan;

Since the performance of its cells can not meet the power requirements of the vehicle, with short continuous mileage, which requires increasing perfection of the charging infrastructure and other facilities, pure electric vehicle has maintained the fuel engine, thus leading to the development of hybrid energy vehicle. This opinion is partial, and viewed from the development progress of vehicle technology, in order to meet the urgent requirements of environment and energy, transformation of the electric system is the main factor, system efficiency is the essence, and high efficiency and energy saving are the most important development direction. The introduction of electric driving technology renders the consumption per hundred kilometers at less than 3 litres, with potential environment efficiency, which is the absolute result of the development of auto technology. Marking the great progress made in auto technology and as a revolution in power technology, electric driving technology is of far-reaching significance. Most importantly, it meets the requirements for environment protection, which, with competitive advantages in performance/price ratio, will be welcome to broad users.

(2) The technological advancement of HEVS is a pretty long development process;

Many domestic and foreign experts are of the opinion that the life span of the internal combustion engine is the life of the hybrid vehicle, whether using gasoline, diesel, natural gas or other fuel, the hybrid energy vehicle will keep on a long-term development and innovation under the promotion of new technology.

(3) The ultimate products of the development of HEVS and FCVS will be identical;

Viewed from the technology of the current hybrid energy vehicle, the emission level of HEVS is higher than that of FCVS for the following reasons: one of its power sources is the traditional combustion engine system, which will, with the advancement of technology, be replaced by the fuel cell system, and a hybrid energy vehicle that reaches zero emission is actually a FCVS vehicle. In other word, the ultimate products of the development of FCVS is HEVS, since FCVS will adopt the current research results on HEVS, such as secondary cell technology, recovery technology of starting energy, hybrid mode control technology, as well as cell energy management technology, etc. It may well be said that the fuel cell vehicle with adoption of those technologies is the hybrid energy vehicle to appear in the future.

In summary, the market development of hybrid energy vehicle should be recognized from the viewpoint of the advancement and development of vehicle technology, and HEVS is of very broad development perspectives.

Special investigation of the “Research on the impact of the full life cycle of hybrid energy vehicle and fuel cell vehicle on economy, environment and energy composition” will be conducted on the basis of this research.

6. Proposal for Developing HEVS and FCVS in China

6.1 Recent Focus and Priority

Principles for Selection and Determination:

- Progress of technology development and its degree of maturity
- Demonstrating operation effects
- Degree of difficulties in realizing industrialization and investment intensity required
- Product costs determined by technical and economic factors as well as recent changing trends of the costs
- Degree of difficulties in constructing corresponding facilities
- Prospects of commercialization

Initial Conclusion:

On the basis of above mentioned six principles, China should attach importance to R&D in HEVS and FCVS in the coming five years.

1) The technical advancement of HEVS is the basis of FCVS, the technical breakthrough of HEVS can support the development of FCVS, but they should have their own emphasis in respect of near-term development goal.

2) As a project featuring industrialization of technology, HEVS should have its key technical hurdles tackled on the basis of referring to foreign experiences, and its progressive results ought to be transformed and industrialized on a timely basis. Mass production that the market will accommodate can hopefully be achieved within 5 years with appropriate support by government policies.

3) It is suggested that a number of key technologies be tackled of FCVS, a key scientific and technological project, on the basis of tracking international development trends, so as to develop a FCVS prototype experimental vehicle whose specifications and performance can meet the requirements for normal driving.

(2) Specific targets

The development targets of HEVS in the coming five years are recommended as follows:

- Complete the development of key technology;
- Research and develop the hybrid energy limousine and buses that can satisfy the business purposes, urban lease and public transportation;
- Form the moderate batch production capacity, and promote the decrease of product costs;
- Organize the running demonstration of HEVS, and gradually establish the related standards and policy system;
- HEVS should reach the following performance indexes (taking hybrid energy large

bus as an example):

- ✓ Length: > 11 meter
- ✓ Weight: < 15 tons
- ✓ Engine: EFI
- ✓ Power: > 105kw/4800
- ✓ Drive motor: 55kw, 312V
- ✓ Max. speed: 85km/h
- ✓ Acceleration ability: 0-50km, 12 seconds
- ✓ Continuously running mileage: > 300km
- ✓ Climbing ability: 20%
- ✓ Capacity: 50 seats
- ✓ Battery: Li (Ni-hydrogen) battery
- ✓ Exhaust: 10% of European No. 2 Standard
- ✓ Be provided with several sub-systems such as entire vehicle running control, energy management and battery monitoring etc..

The development tasks of FCVS in the coming five years mainly include:

- Focus on the development of key technology of FCVS, and achieve the stage results;
- Design and develop the sample FCVS (medium and large buses)
- Carry out the test run and demonstration for FCVS.

6.2 R&D Project

In order to support the research and development of HEVS and FCVS, the development priority should be given to the major key technologies:

HEVS:

- HEVS driving distribution model and its mechanism development
- HEVS whole vehicle and control system optimization design
- HEVS whole vehicle corresponding management development
- HEVS battery development
- Study the national standard system suitable to HEVS (including test specifications, test methods and technical specifications.
- Study and carry out the works in relation to product certification system.

FCVS:

- FCVS power consumption pile development and its optimization of structure
- FCVS engine thermal management system research
- Research in electronic control of FCVS battery auxiliary system
- FCVS whole vehicle corresponding management system development
- FCVS whole vehicle optimization design and matching tests
- Study the national standard system suitable to FCVS (including test specifications, test methods and technical specifications.
- Study and carry out the works in relation to product certification system.

6.3 Demonstration Project

HEVS:

On the basis of R&D, typical cities or regions are selected, and HEVS will be test run and its various performance specifications be demonstrated under different traffic conditions. Specifically, HEVS demonstration fleet can be established and test run on the basis of commercial operations. The demonstration vehicles may come from domestic and overseas manufacturers. For specific method, the project can be operated according to the mode of commercialization under the support of government, the test run and demonstration can be carried out in respects of technology and economy, the practice basis can also be provided for formulation of the related policies.

FCVS:

FCVS prototypes will be test run to provide a basis for improving its performance. For specific method, the single running test can be adopted, or to join in the clean vehicle fleet to carry out the demonstrative running.

6.4 International Cooperation

HEVS:

- Joint cooperative development of HEVS key technologies
- Introduction, digestion and absorption of technologies for economic vehicles
- Joint venture and cooperation in manufacturing HEVS that meet the requirements of the Chinese market
- Technical exchange and discussion of rules and standards for FCVS.

FCVS:

- Seeking cooperative partners, joint key R&D in key technologies
- Joint test running of FCVS within China
- Technical exchange and discussion of rules and standards for FCVS

7. Policy Suggestions on Encouraging HEVS and FCVS Development

7.1 Financial Supporting

The government will directly support the R&D, industrial production, promotion and application of HEVS and FCVS with financial means.

(1) Incorporate HEVS and FCVS development into the governmental scientific plan. Earmark capital to financially support the R&D and operation demonstration.
(2) Include HEVS and FCVS industrialization in national industrial development plan,

and support it with capital investment designated for “pivotal construction projects and key technical reconstruction projects”.

(3) Offer subsidies to the units that undertake the demonstration project and users of HEVS and FCVS.

7.2 Governmental Coordination.

Reinforce the unified organizing and cooperating of governmental departments in the R&D and promotion and application of HEVS and FCVS, establish an effective coordinating mechanism which can play respective advantages of varied departments within current governmental function frame, and form a project organizational management system, which not only mutual links up the R&D with achievement transformation, but also industrial development with the market application.

7.3 Policy Orientation

(1) Use economic leverage such as tax and subsidy, to form a mechanism which will encourage the development and usage of HEVS and FCVS.

(2) Regulate and implement a stricter legal restriction on the emission of the exhaust gas, to provide a bigger pressure and impetus for the development and employment of HEVS and FCVS.

(3) Build an appropriate social atmosphere for developing HEVS and FCVS through ways like model demonstration, public expenditure and governmental procurement.

7.4 Enforcement of Rules and Standards

The enthusiasm of enterprises on development of HEVS and FCVS comes from two aspects, i.e. governmental enforcement and market demand. To issue the compulsory rules and standards at the suitable time will make these two aspects combined with each other organically, so as to promote the successful and healthful development of HEVS and FCVS.

7.5 Recommendation of Organization Form for Project

- Organize and implement the project focused on the backbone enterprises, the government should give its directive financial support in science and technology plan.

- Support backbone enterprises to develop the key vehicles, determine the organization responsible for key technology development by way of bidding. The technical development should be responsible for the enterprises developing the entire vehicle.

- Strengthen the process control and dynamic regulation on project implementation by suitable means.

- The related governments concerned should coordinate and organize the operational demonstration for implementation of project.

- Study and stipulate the related policies and measures to support the industrialization of project, so as to provide the good market environment for development of HEVS.

8. Conclusions and Suggestions

There exists a significant environmental and resource-saving effectiveness, and a potential economic benefit in developing HEVS and FCVS, which represent the direction of the future auto industry, and gives a hard-won opportunity for the Chinese auto industry to leap forward.

The organization and implementation of this project should follow a unified principle linking long-run program with step-by-step implementation, and make overall arrangement according to varied development emphasis and priority.

The government will play an important role in the initial development phase, by directly supporting the start-up, and by creating opportunities for the sustainable development of the project.

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