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Economic and environmental comparison of conventional, hybrid, electric and hydrogen fuel cell vehicles

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Abstract

Published data from various sources are used to perform economic and environmental comparisons of four types of vehicles: conventional, hybrid, electric and hydrogen fuel cell. The production and utilization stages of the vehicles are taken into consideration. The comparison is based on a mathematical procedure, which includes normalization of economic indicators (prices of vehicles and fuels during the vehicle life and driving range) and environmental indicators (greenhouse gas and air pollution emissions), and evaluation of an optimal relationship between the types of vehicles in the fleet. According to the comparison, hybrid and electric cars exhibit advantages over the other types. The economic efficiency and environmental impact of electric car use depends substantially on the source of the electricity. If the electricity comes from renewable energy sources, the electric car is advantageous compared to the hybrid. If electricity comes from fossil fuels, the electric car remains competitive only if the electricity is generated on board. It is shown that, if electricity is generated with an efficiency of about 50–60% by a gas turbine engine connected to a high-capacity battery and an electric motor, the electric car becomes advantageous. Implementation of fuel cells stacks and ion conductive membranes into gas turbine cycles permits electricity generation to increase to the above-mentioned level and air pollution emissions to decrease. It is concluded that the electric car with on-board electricity generation represents a significant and flexible advance in the development of efficient and ecologically benign vehicles.

Keywords: Energy; Environment; Economics; Efficiency; Vehicle; Fuel cell

1. Introduction

The design of modern, effective and environmentally benign cars requires, among other developments, improvements in power train systems and fuel production technologies. Opportunities for utilizing various fuels in vehicle propulsion systems have been analyzed in numerous studies [1–4].

In assessing a vehicle system, the present authors feel it is necessary to consider stages involved in a vehicle's life cycle, which are linked and which range from the extraction of natural resources to produce fuels to the final transformation of fuel to mechanical energy in an engine. The efficiency and environmental impact related to the fuel use are defined by both engine quality and the efficiency and environmental impact associated with the life cycle stages preceding fuel utilization. The overall environmental impact of vehicle use also includes the impacts associated with vehicle production and end-of-life utilization measures, which have been studied as well [5].

The transformation to environmentally benign transportation technologies normally requires that the alternatives also be economically justified and cost effective.

This article evaluates economic and environmental indicators (based on actual data), for vehicle production and utilization stages, and uses them to perform a comparison of four kinds of vehicles: conventional, hybrid, electric and hydrogen fuel cell. The purpose of the article is to obtain information that can assist in the design and development of a contemporary light-duty car, with reasonably superior economic and environmental attributes.

2. Analysis

2.1. Economic criteria

The following criteria are taken to be key economic characteristics of vehicles: vehicle price (including the price for changing

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Nomenclature

AP air pollution
GHG greenhouse gas
Ind indicator*r*
LHV lower heating value (MJ kg^{-1})
m mass (kg)
NGInd normalized general indicator
NiMeH nickel metal hydride
NInd normalized indicator
PEMFC polymer exchange membrane fuel cell
VOC volatile organic compound
w weighting coefficient

Greek symbols
β fraction of a given type of vehicle in a fleet
η efficiency of electricity generation

Subscripts
bat battery
car car
m mass
max maximum
fc fuel cell
i, *j* indexes

batteries for hybrid and electric vehicles), fuel costs (which are related to vehicle lifetime), and driving range (which defines the number of refueling stations required). Four particular vehicles, with release years ranging from 2002 to 2004, are taken as representative of each vehicle category: Toyota Corolla (conventional), Toyota Prius (hybrid), RAV4 EV (electric) and Honda FCX (hydrogen fuel cell). The characteristics of each vehicle are based on published specifications. The price of the Honda FCX fuel cell vehicle is listed as US$ 2,000,000, but can be reduced to US$ 100,000 in regular production [7]. This reduced price is considered here to make the comparisons reasonable. The cost used for batteries is based on a Delphi study [8] that evaluated the cost to be US$ 569 kWh^{-1} for nickel metal hydride (NiMeH) batteries for hybrid and electric cars. We also assume a 40-l tank for conventional and hybrid vehicles in order to calculate driving range. Table 1 lists technical and economic vehicle parameters.

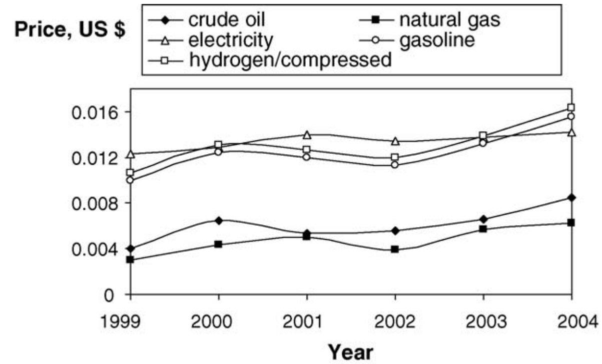

Fig. 1. Prices of selected energy carriers in MJ from 1999 to 2004 [data from ref. [9]].

The average prices of gasoline, hydrogen and electricity for 1999–2004 are used to calculate the prices of fuels (listed in column 3 of Table 1). Fig. 1 represents the prices of the major energy carriers for 1999–2004 based on the data taken from [9]. Data are not available for the price of hydrogen, but according to an analysis [10], which shows the price of gasoline is about two times that of crude oil, the price of hydrogen is about two times that of natural gas. The efficiencies of producing gasoline from crude oil and hydrogen from natural gas are similar [11]. As the prices of natural gas and gasoline have not varied greatly, we assume here that the ratio of price to lower heating value (LHV) of hydrogen is equal to that of gasoline. But because the density of gaseous hydrogen is very low, in order to use it as a fuel in a vehicle, it must be compressed, liquefied or stored in a chemical or physical bonded form. In order to compress hydrogen from 20 atm (the typical pressure after natural gas reforming [12]) to 350 atm (the pressure in the hydrogen tank of the Honda FCX), about 50 kJ of electricity is consumed per MJ of hydrogen on board the vehicle. So, the final price of hydrogen presented in Fig. 1 is therefore slightly higher than that of gasoline.

2.2. Environmental impact criteria

In this study, environmental impact is considered by examining air pollution (AP) and greenhouse gas (GHG) emissions. The

Table 1
Economic characteristics for four vehicle technologies

Type of car	Fuel	Price (thousands US$)	Fuel consumption[a] (MJ per 100 km)	Fuel price (US$ per 100 km)	Driving range (km)	Price of battery changes (changes times price) during life cycle[b] of vehicle (thousands US$)
Conventional	Gasoline	15.3	236.8[c]	2.94	540	1 × 0.1
Hybrid	Gasoline	20.0	137.6	1.71	930	1 × 1.02
Electric	Electricity	42.0	67.2	0.901	164	2 × 15.4
Fuel cell	Hydrogen	100.0	129.5	1.69	355	1 × 0.1

Sources: refs. [6–9].
[a] Fuel consumption based on 45% highway and 55% city driving.
[b] Life cycle of vehicle is taken as 10 years.
[c] Heat content of conventional gasoline is assumed to be its lower heating value (LHV), fixed at 32 MJ l^{-1}.

Table 2
Gaseous emissions per kilogram of curb mass of a typical vehicle

Industrial stage	CO (kg)	NO_x (kg)	GHG emissions (kg)
Extraction	0.0120	0.00506	1.930
Manufacturing	0.000188	0.00240	1.228
End-of-life	1.77×10^{-6}	3.58×10^{-5}	0.014
Total	0.0122	0.00750	3.172

Source: ref. [5].

main gases in GHG emissions are CO_2, CH_4, N_2O and sulfur hexafluoride (SF_6), which have GHG impact weighting coefficients relative to CO_2 of 1, 21, 310 and 24,900, respectively [13]. Sulfur hexafluoride is used as a cover gas in the process of magnesium casting. Impact weighting coefficients (relative to NO_x) for the airborne pollutants CO, NO_x and volatile organic compounds (VOCs) are based on those obtained by the Australian Environment Protection Authority [14] using cost–benefit analyses of health effects. The weighting coefficient of SO_x relative to NO_x is estimated using Ontario air quality index data [15]. Thus, for considerations of air pollution, the airborne pollutants CO, NO_x, SO_x and VOCs are characterized by the following weighting coefficients: 0.017, 1, 1.3 and 0.64, respectively.

The environmental impact related to the vehicle production stage is associated with material extraction and processing, manufacturing and end-of-life utilization steps. Data on the gaseous emissions accompanying a typical vehicle are taken from ref. [5] and presented in Tables 2 and 3. The AP_m emissions per unit curb mass of a conventional car are obtained by applying weighting coefficients to the masses of air pollutants in accordance with the formula:

$$AP_m = \sum_{1}^{4} m_i w_i \tag{1}$$

where i is the index denoting an air pollutant (CO, NO_x, SO_x, VOCs), m_i the mass of air pollutant i, and w_i is the weighting coefficient of air pollutant i. The results of the environmental impact evaluation for the vehicle production stage for the vehicle types considered are presented in Table 3. We assume that GHG and AP emissions are proportional to the vehicle mass, but the environmental impact related to the production of special devices in hybrid, electric and fuel cell cars, e.g., nickel metal hydride (NiMeH) batteries and fuel cell stacks, are evaluated separately. Accordingly, the AP and GHG emissions are calculated for conventional vehicles as

$$AP = m_{car} AP_m \tag{2a}$$

$$GHG = m_{car} GHG_m \tag{2b}$$

for hybrid and electric vehicles as

$$AP = (m_{car} - m_{bat}) AP_m + m_{bat} AP_{bat} \tag{3a}$$

$$GHG = (m_{car} - m_{bat}) GHG_m + m_{bat} GHG_{bat} \tag{3b}$$

and for fuel cell vehicles as

$$AP = (m_{car} - m_{fc}) AP_m + m_{fc} AP_{fc} \tag{4a}$$

$$GHG = (m_{car} - m_{fc}) GHG_m + m_{fc} GHG_{fc} \tag{4b}$$

where m_{car}, m_{bat} and m_{fc} are, respectively, the masses of cars, NiMeH batteries and the fuel cell stack, AP_m, AP_{bat} and AP_{fc} are air pollution emissions per kilogram of conventional vehicle, NiMeH batteries and the fuel cell stack, GHG_m, GHG_{bat} and GHG_{fc} are greenhouse gas emissions per kilogram of conventional vehicle, NiMeH batteries and fuel cell stack. The masses of NiMeH batteries for hybrid and electric cars are 53 kg (1.8 kWh capacity) and 430 kg (27 kWh capacity), respectively. The mass of the fuel cell stack is about 78 kg (78 kW power capacity). According to Rantik [16], the production of 1 kg of NiMeH battery requires 1.96 MJ of electricity and 8.35 MJ of liquid petroleum gas. The environmental impact of battery production is presented in Table 4, assuming that electricity is produced from natural gas with an average 40% efficiency (which is reasonable since the efficiency of electricity production from natural gas varies from 33% for gas turbine units to 55% for combined-cycle power plants, with about 7% of the electricity dissipated during transmission). The material inventory for a polymer exchange membrane fuel cell (PEMFC), from ref. [17], is presented in Table 5. The environmental impact of the fuel cell stack production stage, as calculated by Pehnt [18], is used to express environmental impact in terms of AP and GHG emissions (Table 4, last line). Compared to NiMeH batteries, the data indicate that the PEMFC production stage accounts for relatively large GHG and AP emissions. Manufacturing of electrodes (including material extraction and processing) and bipolar plates constitute a major part of the emissions [18].

GHG and AP emissions also emanate from fuel production and utilization stages. The corresponding environmental impact has been evaluated in numerous life cycle assessments of fuel cycles [1–4]. We have analyzed in previous publications [11,19]

Table 3
Environmental impact associated with vehicle production stages

Type of car	Curb mass (kg)	GHG emissions (kg)	AP emissions (kg)	GHG emissions per 100 km of vehicle travel[a] (kg per 100 km)	AP emissions per 100 km of vehicle travel (kg per 100 km)
Conventional	1134	3595.8	8.74	1.490	0.00362
Hybrid	1311	4156.7	10.10	1.722	0.00419
Electric	1588	4758.3	15.09	1.972	0.00625
Fuel cell	1678	9832.4	42.86	4.074	0.0178

Sources: [5,16,18].
[a] During vehicle's life time (10 years), an average car drives 241,350 km [6].

Table 4
The environmental impact related to the production of nickel metal hydride (NiMeH) batteries and polymer exchange membrane fuel cell (PEMFC) stacks

Equipment	Mass (kg)	Number per life of vehicle	AP emissions per life of vehicle (kg)	GHG emissions per life of vehicle (kg)
NiMeH battery for hybrid car	53	2	0.507	89.37
NiMeH battery for electric car	430	3	6.167	1087.6
PEMFC stack for fuel cell car	78	1	30.52	4758.0

Sources: [8,16,18].

Table 5
Material inventory of a polymer exchange membrane fuel cell stack

Component	Material	Mass (kg)
Electrode	Platinum	0.06
	Ruthenium	0.01
	Carbon paper	4.37
Membrane	Nafion membrane	5.64
Bipolar plate	Polypropylene	16.14
	Carbon fibers	16.14
	Carbon powder	21.52
End-plate	Aluminum alloy	2.80
Current collectors	Aluminum alloy	1.14
Tie-rod	Steel	2.05
Total		69.87

Source: ref. [17].

the data from these studies. Here, the results of that analysis are used.

Three scenarios for electricity production are considered here: (1) electricity is produced from renewable energy sources including nuclear energy; (2) 50% of the electricity is produced from renewable energy sources and 50% from natural gas with an efficiency of 40%; (3) all electricity is produced from natural gas with an efficiency of 40%. Nuclear/renewable weighted average GHG emissions are reported in [20] as 18.4 tonnes CO_2-equivalents per GWh of electricity. These emissions are embedded in material extraction, manufacturing and decommissioning for nuclear, hydro, biomass, wind, solar and geothermal power generation stations. AP emissions are calculated assuming that GHG emissions for plant manufacturing correspond entirely to natural gas combustion. GHG and AP emissions embedded in manufacturing a natural gas power generation plant are negligible compared to the direct emissions during its utilization [21]. Taking all these factors into account, GHG and AP emissions for the three scenarios for electricity generation are calculated and presented in Table 6.

Table 6
Greenhouse gas and air pollution emissions per MJ of electricity produced

Scenario	GHG emission (g)	AP emission (g)
Scenario 1[a]	5.11	0.0195
Scenario 2	77.5	0.296
Scenario 3	149.9	0.573

[a] *Source:* ref. [20].

Table 7
Greenhouse gas and air pollution emissions per MJ (LHV) of hydrogen and gasoline from combustion in fuel cell and internal combustion engine vehicles

Fuels	GHG emission (g)	AP emission (g)
Hydrogen from natural gas		
Scenario 1	78.5	0.0994
Scenario 2	82.1	0.113
Scenario 3	85.7	0.127
Gasoline from crude oil	84.0	0.238

Sources: refs. [1–4,11,19].

As noted above, hydrogen use in a fuel cell vehicle requires its compression and, as a consequence, electricity to power a compressor. Table 7 lists GHG and AP emissions from gasoline and hydrogen utilization in vehicles depending on the electricity-generation scenario.

Table 8 presents the environmental impact as a result of the fuel utilization stage, and the overall environmental impact, which includes the fuel utilization and car production stages.

2.3. Normalization and general indicator

To allow different cars to be compared when different kinds of indicators are available, a normalization procedure is performed. The value of a normalized indicator of 1 is chosen to correspond to the best economic and environmental performance among the cars considered. Therefore, normalized indicators for vehicle and fuel costs, and greenhouse gas and air pollution emissions, are proposed according to the following expression:

$$(\text{NInd})_i = \frac{(1/\text{Ind})_i}{(1/\text{Ind})_{\max}} \quad (5)$$

where $(1/\text{Ind})_i$ are the reciprocal values of indicators like vehicle and fuel costs, greenhouse gas and air pollution emissions (see Tables 1 and 8), $(1/\text{Ind})_{\max}$ the maximum of the reciprocal values of those indicators, $(\text{NInd})_i$ the normalized indicator, and the index i denotes the vehicle type (from the four kinds of vehicles considered here).

But for driving range (distance on one full tank of fuel or on one full charge of batteries) indicators, the normalized indicators $(\text{NInd})_i$ are expressible as

$$(\text{NInd})_i = \frac{(\text{Ind})_i}{(\text{Ind})_{\max}} \quad (6)$$

where $(\text{Ind})_i$ denotes the driving range indicator for the four types of vehicles (implied by index i) considered here, and $(\text{Ind})_{\max}$ denotes the maximum value of the driving range indicator.

Table 8
Greenhouse gas and air pollution emissions related to the fuel utilization stage and total environmental impact for different types of cars

Car type	Fuel utilization stage		Total	
	GHG emissions per 100 km of vehicle travel (kg per 100 km)	AP emissions per 100 km of vehicle travel (kg per 100 km)	GHG emissions per 100 km of vehicle travel[a] (kg per 100 km)	AP emissions per 100 km of vehicle travel (kg per 100 km)
Conventional	19.9	0.0564	21.4	0.0600
Hybrid	11.6	0.0328	13.3	0.0370
1[b]				
Electric	0.343	0.00131	2.31	0.00756
Fuel cell	10.2	0.0129	14.2	0.0306
2				
Electric	5.21	0.0199	7.18	0.0262
Fuel cell	10.6	0.0147	14.7	0.0324
3				
Electric	10.1	0.0385	12.0	0.0448
Fuel cell	11.1	0.0165	15.2	0.0342

[a] During vehicle life time (10 years), an average car drives 241,350 km [6].
[b] Numbers in this column denote scenario for electricity production.

After normalization of the information, normalized economic and environmental indicators for four types of vehicles are obtained for the three scenarios of electricity generation (Table 9). The generalized indicator represents the product of the calculated normalized indicators (which is a simple geometrical aggregation of criteria with an absence of weighting coefficients). The "ideal car" is associated with a generalized indicator of 1, as such a vehicle possesses all the advantages of those considered. The calculated values of general indicators provide a measure of "how far" a given car is from the ideal one, for the factors considered.

3. Results and discussion

To simplify the comparisons of the vehicles, the general indicator also has been normalized according to Eq. (6). Fig. 2 shows

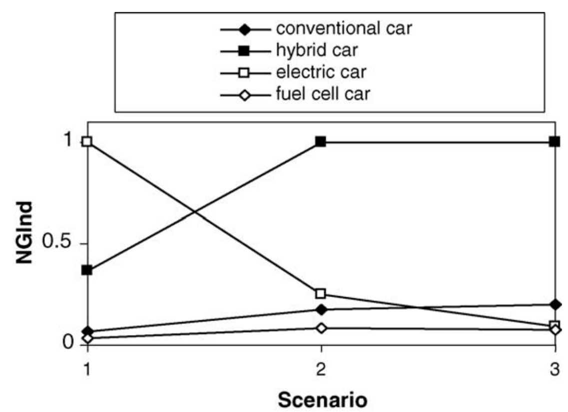

Fig. 2. The dependence of the normalized general indicator, NGInd, on electricity-generation scenario for four types of cars.

Table 9
Normalized economic and environmental indicators for four types of cars

Car type	Normalized indicators					General indicator	Normalized general indicator
	Car cost	Range	Fuel cost	Greenhouse gas emissions	Air pollution emissions		
1[a]							
Conventional	1	0.581	0.307	0.108	0.126	0.00243	0.0651
Hybrid	0.733	1	0.528	0.174	0.205	0.0138	0.370
Electric	0.212	0.177	1	1	1	0.0374	1
Fuel cell	0.154	0.382	0.532	0.163	0.247	0.00126	0.0336
2							
Conventional	1	0.581	0.307	0.336	0.436	0.0261	0.176
Hybrid	0.733	1	0.528	0.541	0.708	0.148	1
Electric	0.216	0.177	1	1	1	0.0374	0.252
Fuel cell	0.154	0.382	0.532	0.488	0.807	0.0123	0.0832
3							
Conventional	1	0.581	0.307	0.599	0.628	0.0670	0.197
Hybrid	0.733	1	0.528	0.911	0.967	0.341	1
Electric	0.212	0.177	1	1	0.824	0.0308	0.0903
Fuel cell	0.154	0.382	0.532	0.794	1	0.0248	0.0728

[a] Numbers in this column denote scenario for electricity generation.

Table 10
Optimal relationship in fleet between different types of cars

Scenario for electricity generation	Conventional car (%)	Hybrid car (%)	Electric car (%)	Fuel cell (%)	General indicator
1	0	38	62	0	0.079
2	0	78	22	0	0.159
3	0	100	0	0	0.341

the dependence of the normalized general indicator NGInd (column 8 in Table 9) on the electricity-generation scenario. According to those results, hybrid and electric cars are competitive if nuclear and renewable energies account for about 50% of the energy to generate electricity. If fossil fuels (in this case natural gas) are used for more than 50% of the energy to generate electricity, the hybrid car has significant advantages over the other three.

An optimization has been performed to obtain the optimal relationship between vehicles in a fleet. The optimal relationship is considered here to be the maximum value of the general indicator in accordance with following equations:

$$\sum_{i=1}^{4} \beta_i = 1 \tag{7}$$

$$\prod_{j=1}^{5} \sum_{i=1}^{4} \beta_i \cdot \mathrm{NInd}_i^j = \text{maximum} \tag{8}$$

where β_i is the fraction of a given type of car in the fleet, NInd_i^j is the normalized economic or environmental indicator for a given type of car, the index i denotes the vehicle type, and the index j denotes the five kinds of economic and environmental indicators from Table 9.

Table 10 presents the optimal relationship between different types of cars in the fleet, depending on the scenario for electricity generation. The best result occurs for a fleet of 20% of hybrid cars and 80% of electric cars for scenario 1 for electricity generation. If the nuclear and renewable energy fraction is reduced (scenarios 2 and 3), the electric car becomes uncompetitive with respect to the hybrid car. The hydrogen fuel cell car is not competitive for the all scenarios considered here, but it has the best air pollution emissions indicator for scenario 3. This result is in line with those in publications considering hydrogen fuel cell cars [1–4].

As seen in Table 9 (scenario 3), the electric car is inferior to the hybrid one in terms of car price, range and air pollution emissions. The simplest technical solution to increase its range is to produce electricity on-board the vehicle. Since the efficiency of electricity generation by means of an internal combustion engine is lower than that of a gas turbine unit (typically the efficiency of a thermodynamic cycle with fuel combustion at constant pressure is higher than for one at constant volume [22]), it could make sense on thermodynamic grounds to incorporate a gas turbine engine into an electric car. The application of fuel cell systems (especially solid oxide fuel cell stacks) within gas turbine cycles allows their efficiency to be increased to 60% [23].

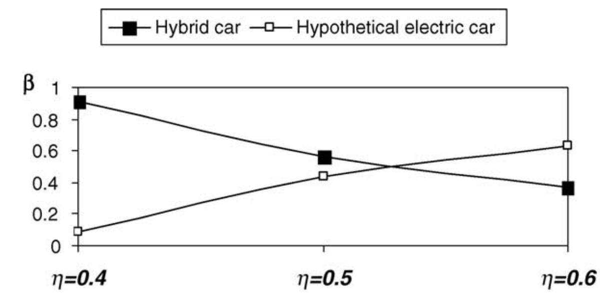

Fig. 3. The optimal fraction (β) for hybrid and hypothetical electric cars in the fleet.

The pressure of the natural gas required to attain a range equal to the range of a hybrid car is more than two times less than the pressure of hydrogen in the tank of the fuel cell vehicle. So, corresponding to the efficiency of electricity generation from natural gas $\eta = 0.4$–0.6, the required pressure in the tank of a hypothetical electric car could be reduced to 115 atm.

Assuming the cost and GHG and AP emissions corresponding to the hypothetical electric car production stage are equal to those for the electric prototype, the normalized indicators for the different on-board electricity-generation efficiencies can be calculated (see Table 11). An optimization is needed to obtain the optimal relationship between capacities of batteries and a gas turbine engine. Fig. 3 presents the optimal fractions of hybrid and hypothetical electric cars in a fleet to increase the general indicators in Table 11. From Table 11 and Fig. 3, it can be seen that if electricity is generated with an efficiency of about 50–60% by a gas turbine engine connected to a high-capacity battery and electric motor, the electric car becomes superior.

Table 11
Normalized economic and environmental indicators for hybrid and hypothetical electric car with different efficiencies for on-board electricity generation

Car type	Normalized indicators					General indicator
	Car cost	Range	Fuel cost	Greenhouse gas emissions	Air pollution emissions	
Hybrid	1	1	0.316	0.720	0.954	0.217
Electric, $\eta = 0.4$	0.289	1	0.663	0.725	0.718	0.0997
Electric, $\eta = 0.5$	0.289	1	0.831	0.867	0.863	0.180
Electric, $\eta = 0.6$	0.289	1	1	1	1	0.289

The gas turbine engine has many advantages over the conventional internal combustion engine: the opportunity to use various kinds of liquid and gaseous fuels, quick starts at low air temperatures, high traction qualities and simplicity of design. The main reason the implementation of gas turbine engines into light-duty vehicles in the 1960s failed was their poor ability to change fuel consumption with varying traffic conditions. Then, the gas turbine engine was considered for use in directly converting fuel energy into mechanical work to drive an automobile. The application of a gas turbine unit only to generate electricity, permits this weakness to be overcome, when the gas turbine is integrated with a high-capacity battery and electric motor.

The introduction of ion conductive membranes and fuel cells into a gas-turbine cycle can further increase the efficiency and decrease AP emissions [24].

4. Conclusions

Using actual data, an economic and environmental comparison is performed of four types of vehicles: conventional, hybrid, electric and hydrogen fuel cell. The analysis shows that the hybrid and electric cars have advantages over the others. The economics and environmental impact associated with use of an electric car depends substantially on the source of the electricity. If electricity comes from renewable energy sources, the electric car is advantageous to the hybrid vehicle. If the electricity comes from fossil fuels, the electric car remains competitive only if the electricity is generated on-board. If the electricity is generated with an efficiency of about 50–60% by a gas turbine engine connected to a high-capacity battery and electric motor, the electric car becomes superior in many respects. The implementation of fuel cells stacks and ion conductive membranes into gas turbine cycles could permit electricity-generation efficiency to be further increased and air pollution emissions to be further decreased. It is concluded, therefore, that the electric car with capability for on-board electricity generation represents a beneficial option worthy of further investigation in the development of energy efficient and ecologically benign vehicles. This conclusion is also in line with the analysis presented in [25], which was performed by an electric and hybrid vehicle consultant. The main limitations of this study follow: (i) the use of data which may be controversial in some instances; (ii) subjective choice of indicators; and (iii) the simple procedure applied for building up the general indicator without using unique weighting coefficients. In spite of these limitations, the authors feel that the study reflects relatively accurately and realistically the circumstances at this time.

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