

Module 1: History of Electrical Vehicle

Lecture 1: Introduction to Hybrid Electric Vehicles

Historical Journey of Hybrid and Electric Vehicles

Introduction:

What is a hybrid? A hybrid vehicle combines any two power (energy) sources. Possible combinations include diesel/electric, gasoline/fly wheel, and fuel cell (FC)/battery. Typically, one energy source is storage, and the other is conversion of a fuel to energy. The combination of two power sources may support two separate propulsion systems. Thus to be a True hybrid, the vehicle must have at least two modes of propulsion.

For example, a truck that uses a diesel to drive a generator, which in turn drives several electrical motors for all-wheel drive, is *not a hybrid*. But if the truck has electrical energy storage to provide a second mode, which is electrical assists, then it is a hybrid Vehicle.

These two power sources may be paired in series, meaning that the gas engine charges the batteries of an electric motor that powers the car, or in parallel, with both mechanisms driving the car directly.

Hybrid electric vehicle (HEV)

Consistent with the definition of hybrid above, the hybrid electric vehicle combines a gasoline engine with an electric motor. An alternate arrangement is a diesel engine and an electric motor (figure 1).

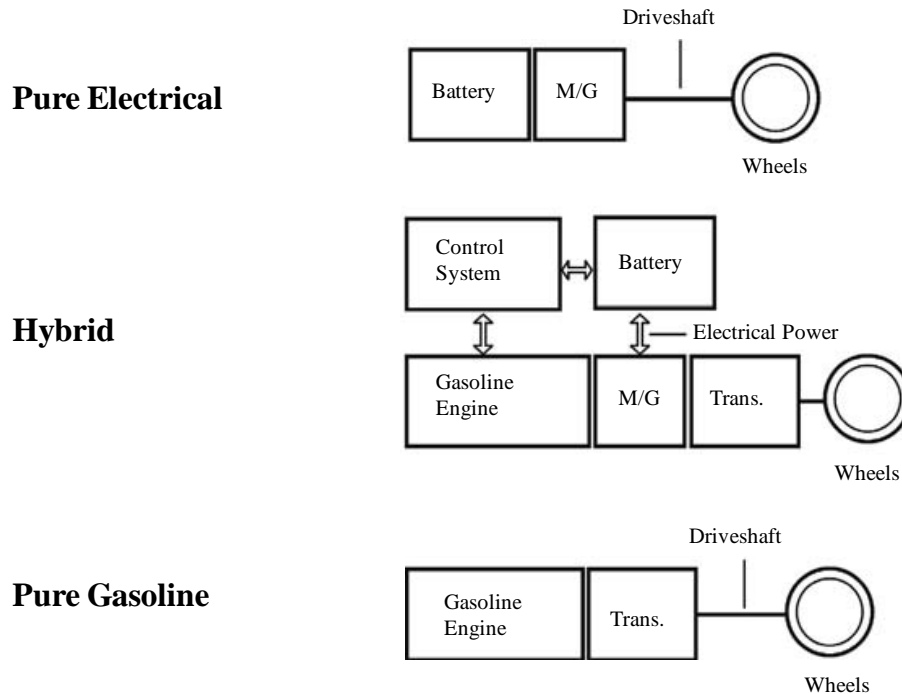


Figure 1: Components of a hybrid Vehicle that combines a pure gasoline with a pure EV. [1]

As shown in **Figure 1**, a HEV is formed by merging components from a pure electrical vehicle and a pure gasoline vehicle. The Electric Vehicle (EV) has an M/G which allows regenerative braking for an EV; the M/G installed in the HEV enables regenerative braking. For the HEV, the M/G is tucked directly behind the engine. In Honda hybrids, the M/G is connected directly to the engine. The transmission appears next in line. This arrangement has two torque producers; the M/G in motor mode, M-mode, and the gasoline engine. The battery and M/G are connected electrically.

HEVs are a combination of electrical and mechanical components. Three main sources of electricity for hybrids are batteries, FCs, and capacitors. Each device has a low cell voltage, and, hence, requires many cells in series to obtain the voltage demanded by an HEV. Difference in the source of Energy can be explained as:

- a. The FC provides high energy but low power.
- b. The battery supplies both modest power and energy.
- c. The capacitor supplies very large power but low energy.

The components of an electrochemical cell include anode, cathode, and electrolyte (shown in fig2). The current flow both internal and external to the cell is used to describe the current loop.

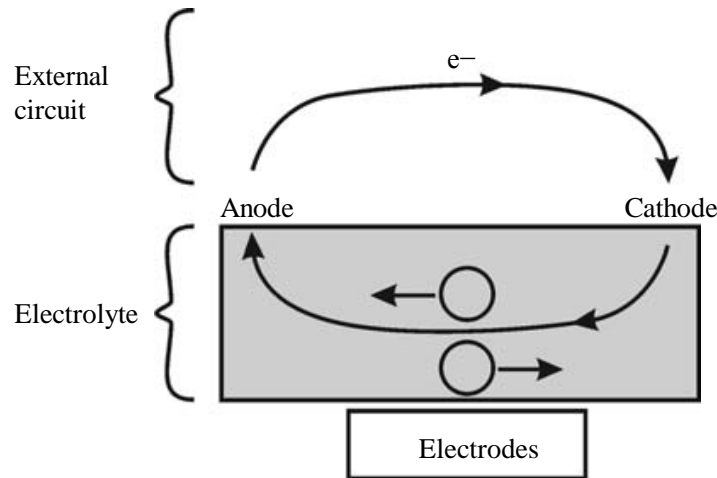


Figure 2: An electrode, a circuit for a cell which is converting chemical energy to electrical energy. The motion of negative charges is clockwise and forms a closed loop through external wires and load and the electrolyte in the cell. [1]

A critical issue for both battery life and safety is the precision control of the Charge/Discharge cycle. Overcharging can be traced as a cause of fire and failure.

Applications impose two boundaries or limitations on batteries. The first limit, which is dictated by battery life, is the minimum allowed State of Charge. As a result, not all the installed battery energy can be used. The battery feeds energy to other electrical equipment, which is usually the inverter. This equipment can use a broad range of input voltage, but cannot accept a low voltage. The second limit is the minimum voltage allowed from the battery.

Historical development (root) of Automobiles

In 1900, steam technology was advanced. The advantages of *steam-powered cars* included high performance in terms of power and speed. However, the disadvantages of steam-powered cars included poor fuel economy and the need to “fire up the boiler” before driving. Feed water was a necessary input for steam engine, therefore could not tolerate the loss of fresh water. Later, Steam condensers were applied to the steam car to solve the feed water problem. However, by that time Gasoline cars had won the marketing battle.

Gasoline cars of 1900 were noisy, dirty, smelly, cantankerous, and unreliable. In comparison, electric cars were comfortable, quiet, clean, and fashionable. Ease of control was also a desirable feature. Lead acid batteries were used in 1900 and are still used in modern cars. Hence lead acid batteries have a long history (since 1881) of use as a viable energy storage device. Golden age of *Electrical vehicle* marked from 1890 to 1924 with peak production of electric vehicles in 1912. However, the range was limited by energy storage in the battery. After every trip, the battery required recharging. At the 1924 automobile show, no electric cars were on display. This announced the end of the Golden Age of electric-powered cars.

The range of a *gasoline car* was far superior to that of either a steam or an electric car and dominated the automobile market from 1924 to 1960. The gasoline car had one dominant feature; it used gasoline as a fuel. The modern period starts with the oil embargoes and the gasoline shortages during the 1970s which created long lines at gas stations. Engineers recognized that the good features of the gasoline engine could be combined with those of the electric motor to produce a superior car. A marriage of the two yields the hybrid automobile.

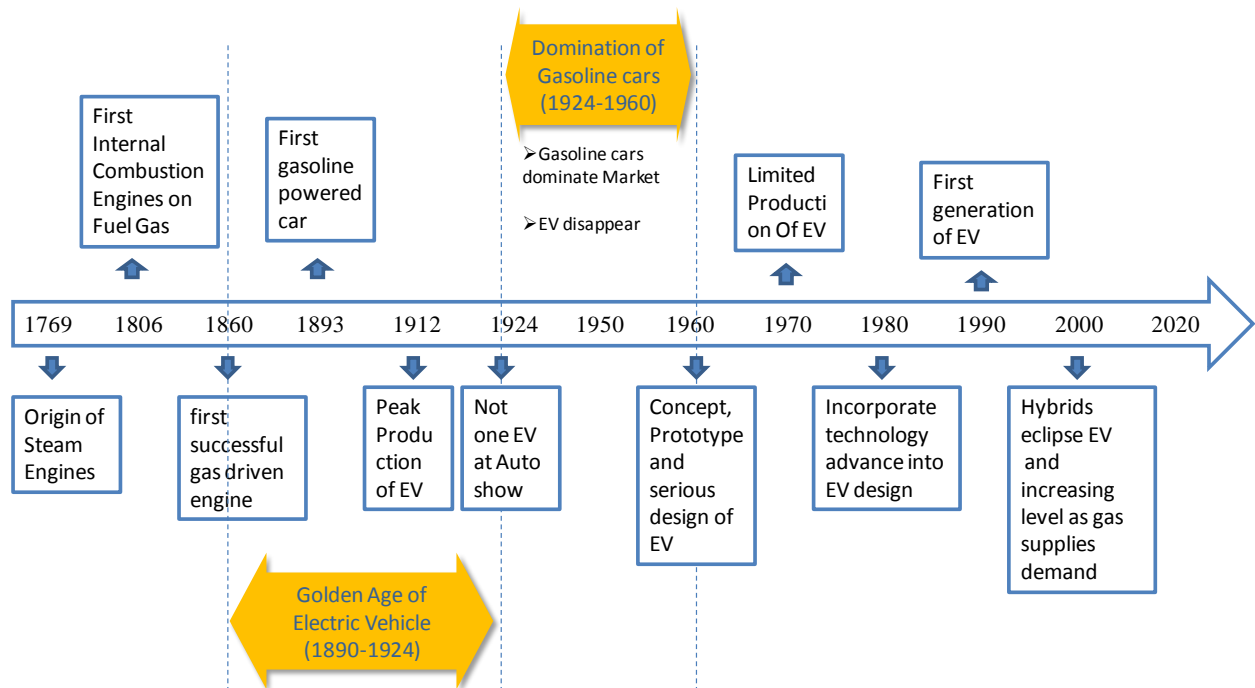


Figure 3: Historical development of automobile and development of interest and activity in the EV from 1890 to present day.

Electric Vehicle merged into hybrid electric vehicle. [1]

1769

The *first steam-powered vehicle* was designed by Nicolas-Joseph Cugnot and constructed by M. Brezin that could attain speeds of up to 6 km/hour. These early steam-powered vehicles were so heavy that they were only practical on a perfectly flat surface as strong as iron.

1807

The next step towards the development of the car was the invention of the internal combustion engine. Francois Isaac de Rivaz designed the *first internal combustion engine* in, using a mixture of hydrogen and oxygen to generate energy.

1825

British inventor Goldsworthy Gurney built a steam car that successfully completed an 85 mile round-trip journey in ten hours time.

1839

Robert Anderson of Aberdeen, Scotland built the *first electric vehicle*.

1860

In, Jean Joseph Etienne Lenoir, a Frenchman, built the *first successful two-stroke gas driven engine*.

1886

Historical records indicate that *an electric-powered taxicab*, using a battery with 28 cells and a small electric motor, was introduced in England.

1888

Immisch & Company built a four-passenger carriage, powered by a one-horsepower motor and 24-cell battery, for the Sultan of the Ottoman Empire. In the same year, Magnus Volk in Brighton, England made a three-wheeled electric car. **1890 – 1910** *(Period of significant improvements in battery technology)*

Invention Of hybrid vehicle

1890

Jacob Lohner, a coach builder in Vienna, Austria, foresaw the need for an electric vehicle that would be less noisy than the new gas-powered cars. He commissioned a design for an electric vehicle from Austro-Hungarian engineer Ferdinand Porsche, who had recently graduated from the Vienna Technical College. Porsche's first version of the electric car used a pair of electric motors mounted in the front wheel hubs of a conventional car. The car could travel up to 38 miles. To extend the vehicle's range, Porsche added a gasoline engine that could recharge the batteries, thus giving birth to the first hybrid, the *Lohner-Porsche Elektromobil*.

Early Hybrid Vehicles

1900

Porsche showed his hybrid car at the Paris Exposition of 1900. A gasoline engine was used to power a generator which, in turn, drove a small series of motors. The electric engine was used to give the car a little bit of extra power. This method of *series hybrid engine* is still in use today, although obviously with further scope of performance improvement and greater fuel savings.

1915

Woods Motor Vehicle manufacturers created the Dual Power hybrid vehicle, second hybrid car in market. Rather than combining the two power sources to give a single output of power, the Dual Power used an electric battery motor to power the engine at low speeds (below 25km/h) and used the gasoline engine to carry the vehicle from these low speeds up to its 55km/h maximum speed. While Porsche had invented the series hybrid, Woods invented the parallel hybrid.

1918

The Woods Dual Power was the *first hybrid to go into mass production*. In all, some 600 models were built by. However, the evolution of the internal combustion engine left electric power a marginal technology

1960

Victor Wouk worked in helping create numerous hybrid designs earned him the nickname of the “Godfather of the Hybrid”. In 1976 he even converted a Buick Skylark from gasoline to hybrid.

1978

Modern hybrid cars rely on the regenerative braking system. When a standard combustion engine car brakes, a lot of power is lost because it dissipates into the atmosphere as heat. Regenerative braking means that the electric motor is used for slowing the car and it essentially collects this power and uses it to help recharge the electric batteries within the car. This development alone is believed to have progressed hybrid vehicle manufacture significantly. The Regenerative Braking System, was first designed and developed in 1978 by David Arthurs. Using standard car components he converted an Opel GT to offer 75 miles to the gallon and many home conversions are done using the plans for this system that are still widely available on the Internet.

Modern Period of Hybrid History

The history of hybrid cars is much longer and more involved than many first imagine. It is, however, in the last ten years or so that we, as consumers, have begun to pay more attention to the hybrid vehicle as a viable alternative to ICE driven cars. Whether looking for a way to save money on spiraling gas costs or in an attempt to help reduce the negative effects on the environment we are buying hybrid cars much more frequently.

1990s

Automakers took a renewed interest in the hybrid, seeking a solution to dwindling energy supplies and environmental concerns and created modern history of hybrid car

1993

In USA, Bill Clinton's administration recognized the urgency for the mass production of cars powered by means other than gasoline. Numerous government agencies, as well as Chrysler, Ford, GM, and USCAR combined forces in the PNGV (Partnership for a New Generation of Vehicles), to create cars using alternative power sources, including the development and improvement of hybrid electric vehicles.

1997

The Audi Duo was the first European hybrid car put into mass production and hybrid production and consumer take up has continued to go from strength to strength over the decades.

2000

Toyota Prius and Honda Insight became the first mass market hybrids to go on sale in the United States, with dozens of models following in the next decade. The Honda Insight and Toyota Prius were two of the first mainstream Hybrid Electric Vehicles and both models remain a popular line.

2005

A hybrid Ford Escape, the SUV, was released in 2005. Toyota and Ford essentially swapped patents with one another, Ford gaining a number of Toyota patents relating to hybrid technology and Toyota, in return, gaining access to Diesel engine patents from Ford.

Present of Hybrid Electric vehicle

Toyota is the most prominent of all manufacturers when it comes to hybrid cars. As well as the specialist hybrid range they have produced hybrid versions of many of their existing model lines, including several Lexus (now owned and manufactured by Toyota) vehicles. They have also stated that it is their intention to release a hybrid version of every single model they release in the coming decade. As well as cars and SUVs, there are a select number of hybrid motorcycles, pickups, vans, and other road going vehicles available to the consumer and the list is continually increasing.

Future of Hybrid electrical vehicle

Since petroleum is limited and will someday run out of supply. In the arbitrary year 2037, an estimated one billion petroleum-fueled vehicles will be on the world's roads. gasoline will become prohibitively expensive. The world need to have solutions for the “**400 million otherwise useless cars**”. So year 2037 “gasoline runs out year” means, petroleum will no longer be used for personal mobility. A market may develop for solar-powered EVs of the size of a scooter or golf cart. Since hybrid technology applies to heavy vehicles, hybrid buses and hybrid trains will be more significant.

References:

[1] A. E. Fuhs, *Hybrid Vehicles and the Future of Personal Transportation*, CRC Press, 2009

Lecture 2: Economic and Environmental Impact of Electric Hybrid Vehicle

Economic and Environmental Impact of Electric Hybrid Vehicle

As modern culture and technology continue to develop, the growing presence of global warming and irreversible climate change draws increasing amounts of concern from the world's population. It has only been recently, when modern society has actually taken notice of these changes and decided that something needs to change if the global warming process is to be stopped.

Countries around the world are working to drastically reduce CO₂ emissions as well as other harmful environmental pollutants. Amongst the most notable producers of these pollutants are automobiles, which are almost exclusively powered by internal combustion engines and spew out unhealthy emissions.

According to various reports, cars and trucks are responsible for almost 25% of CO₂ emission and other major transportation methods account for another 12%. With immense quantities of cars on the road today, pure combustion engines are quickly becoming a target of global warming blame. One potential alternative to the world's dependence on standard combustion engine vehicles are hybrid cars. Cost-effectiveness is also an important factor contributing to the development of an environment friendly transportation sector.

Hybrid Vehicle

A hybrid vehicle combines any type of two power (energy) sources. Possible combinations include diesel/electric, gasoline/fly wheel, and fuel cell (FC)/battery. Typically, one energy source is storage, and the other is conversion of a fuel to energy. In the majority of modern hybrids, cars are powered by a combination of traditional gasoline power and the addition of an electric motor.

However, hybrid still use the petroleum based engine while driving so they are not completely clean, just cleaner than petroleum only cars. This enables hybrid cars to have the potential to segue into new technologies that rely strictly on alternate fuel sources.

The design of such vehicles requires, among other developments, improvements in power train systems, fuel processing, and power conversion technologies. Opportunities for utilizing various fuels for vehicle propulsion, with an emphasis on synthetic fuels (e.g., hydrogen, biodiesel,

bioethanol, dimethylether, ammonia, etc.) as well as electricity via electrical batteries, have been analyzed over the last decade.

In order to analyze environment impact of vehicle propulsion and fueling system; we are presenting a case study which has been reported in literature (*Chapter: Ibrahim Dincer, Marc A. Rosen and Calin Zamfirescu, "Economic and Environmental Comparison of Conventional and Alternative Vehicle Options", Book: Electric and Hybrid Vehicles: Power Sources, Models, Sustainability, Infrastructure and the Market by Gianfranco Pistoia (2010)*)

A Case study

This case treated the following aspects: economic criteria, environmental criteria, and a combined impact criterion. The latter is a normalized indicator that takes into account the effects on both environmental and economic performance of the options considered.

Case compared four kinds of fuel-propulsion vehicle alternatives. Two additional kinds of vehicles, both of which are zero polluting at fuel utilization stage (during vehicle operation) were also included in analysis. The vehicles analyzed were as follows:

1. Conventional gasoline vehicle (gasoline fuel and ICE),
2. Hybrid vehicle (gasoline fuel, electrical drive, and large rechargeable battery),
3. Electric vehicle (high-capacity electrical battery and electrical drive/generator),
4. Hydrogen fuel cell vehicle (high-pressure hydrogen fuel tank, fuel cell, electrical drive),
5. Hydrogen internal combustion vehicle (high-pressure hydrogen fuel tank and ICE),
6. Ammonia-fueled vehicle (liquid ammonia fuel tank, ammonia thermo-catalytic decomposition and separation unit to generate pure hydrogen, hydrogen-fueled ICE).

For **environmental impact analysis**, all stages of the life cycle were considered, starting from

- a) The extraction of natural resources to produce materials and
- b) Ending with conversion of the energy stored onboard the vehicle into mechanical energy for vehicle displacement and
- c) Other purposes (heating, cooling, lighting, etc.).

In addition, vehicle production stages and end-of-life disposal contribute substantially when quantifying the life cycle environmental impact of fuel-propulsion alternatives.

The analysis were conducted on six vehicles, each was representative of one of the above discussed categories. The specific vehicles were:

- 1) Toyota Corolla (conventional vehicle),
- 2) Toyota Prius (hybrid vehicle),
- 3) Toyota RAV4EV (electric vehicle),
- 4) Honda FCX (hydrogen fuel cell vehicle),
- 5) Ford Focus H₂-ICE (hydrogen ICE vehicle),
- 6) Ford Focus H₂-ICE adapted to use ammonia as source of hydrogen (ammonia-fueled ICE vehicle).

Economical Analysis

A number of key economic parameters that characterize vehicles were:

- A. Vehicle price,
- B. Fuel cost, and
- C. Driving range.

This case neglected maintenance costs; however, for the hybrid and electric vehicles, the cost of battery replacement during the lifetime was accounted for. The driving range determines the frequency (number and separation distance) of fueling stations for each vehicle type. The total fuel cost and the total number of kilometers driven were related to the vehicle life (see Table 1).

Table1: Technical and economical values for selected vehicle types

Vehicle type	Fuel Type	Initial Price (USk\$)	Specific fuel Price (US\$/100 km)	Driving Range (Km)	Price of battery Changes During Vehicle Life cycle (USk\$)
Conventional (<i>Toyota Corolla</i>)	Gasoline	15.3	2.94	540	1 x 0.1
Hybrid (<i>Toyota Prius</i>)	Gasoline	20	1.71	930	1 x 1.02
Electric (<i>Toyota RAV4EV</i>)	Electricity	42	0.901	164	2 x 15.4
Fuel cell (<i>Honda FCX</i>)	Hydrogen	100	1.69	355	1 x 0.1
H ₂ -ICE (<i>Ford Focus H₂-ICE</i>)	Hydrogen	60	8.4	300	1 x 0.1
NH ₃ -H ₂ -ICE (<i>Ford Focus H₂-ICE and ammonia Adaptive</i>)	Ammonia	40	6.4	430	1 x 0.1

For the Honda FCX the listed initial price for a prototype leased in 2002 was USk\$2,000, which is estimated to drop below USk\$100 in regular production. Currently, a Honda FCX can be leased for 3 years with a total price of USk\$21.6. In order to render the comparative study reasonable, the initial price of the hydrogen fuel cell vehicle is assumed here to be USk\$100. For electric vehicle, the specific cost was estimated to be US\$569/kWh with nickel metal hydride (NiMeH) batteries which are typically used in hybrid and electric cars.

Historical prices of typical fuels were used to calculate annual average price.

Environmental Analysis

Analysis for the first five options was based on published data from manufacturers. The results for the sixth case, i.e. the ammonia-fueled vehicle, were calculated from data published by Ford on the performance of its hydrogen-fueled Ford Focus vehicle. Two environmental impact elements were accounted for in the:

- a) Air pollution (AP) and
- b) Greenhouse gas (GHG) emissions.

The main GHGs were CO₂, CH₄, N₂O, and SF₆ (sulfur hexafluoride), which have GHG impact weighting coefficients relative to CO₂ of 1, 21, 310, and 24,900, respectively.

For AP, the airborne pollutants CO, NO_x, SO_x, and VOCs are assigned the following weighting coefficients: 0.017, 1, 1.3, and 0.64, respectively.

The vehicle production stage contributes to the total life cycle environmental impact through the pollution associated with

- a) The extraction and processing of material resources,
- b) Manufacturing and
- c) The vehicle disposal stage.

Additional sources of GHG and AP emissions were associated with the fuel production and utilization stages. The environmental impacts of these stages have been evaluated in numerous life cycle assessments of fuel cycles.

Regarding electricity production for the electric car case, three case scenarios were considered here:

1. when electricity is produced from renewable energy sources and nuclear energy;
2. when 50% of the electricity is produced from renewable energy sources and 50% from natural gas at an efficiency of 40%;
3. when electricity is produced from natural gas at an efficiency of 40%.

AP emissions were 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 were negligible compared to the direct emissions during its utilization. Taking those factors into account, GHG and AP emissions for the three scenarios of electricity generation were presented in Table 2.

Table2: GHG and air pollution emissions per MJ of electricity produced

Electricity-generation scenario	Description of Electricity generation Scenario	GHG emission (g)	AP emission (g)
1	Electricity produced = 100% (Renewable Energy + Nuclear Energy)	5.11	0.195
2	Electricity produced = (50% Renewable Energy + 50% Natural gas)	77.5	0.296
3	Electricity produced = 100% Natural Gas	149.9	0.573

Hydrogen charging of fuel tanks on vehicles requires compression. Therefore, presented case considered the energy for hydrogen compression to be provided by electricity.

Table 3: GHG and air pollution emissions per MJ fuel of Hydrogen from natural gas produced

Fuel	GHG emissions, g	AP emissions, g
Hydrogen from natural gas		
Scenario 1	78.5	0.0994
Scenario 2	82.1	0.113
Scenario 3	85.7	0.127

GHG and AP emissions were reported for hydrogen vehicles for the three electricity-generation scenarios considered (see table 3), accounting for the environmental effects of hydrogen compression

Table 4. Environmental impact associated with vehicle Overall Life cycle and Fuel Utilization State

Vehicle type	Fuel utilization stage		Overall life cycle	
	GHG emissions	AP emissions	GHG emissions	AP emissions
	(kg/100 km)	(kg/100 km)	(kg/100 km)	(kg/100 km)
Conventional	19.9	0.0564	21.4	0.06
Hybrid	11.6	0.0328	13.3	0.037
Electric-S1	0.343	0.00131	2.31	0.00756
Electric-S2	5.21	0.0199	7.18	0.0262
Electric-S3	10.1	0.0385	12	0.0448
Fuel Cell -S1	10.2	0.0129	14.2	0.0306
Fuel Cell -S2	10.6	0.0147	14.7	0.0324
Fuel Cell -S3	11.1	0.0165	15.2	0.0342
H2-ICE	10	0.014	11.5	0.018
NH3–H2-ICE	0	0.014	1.4	0.017

The environmental impact of the fuel utilization stage, as well as the overall life cycle is presented in Table 4. The H2-ICE vehicle results were based on the assumption that the only GHG emissions during the utilization stage were associated with the compression work, needed to fill the fuel tank of the vehicle. The GHG effect of water vapor emissions was neglected in this analysis due its little value,. For the ammonia fuel vehicle, a very small amount of pump work was needed therefore, ammonia fuel was considered to emit no GHGs during fuel utilization.

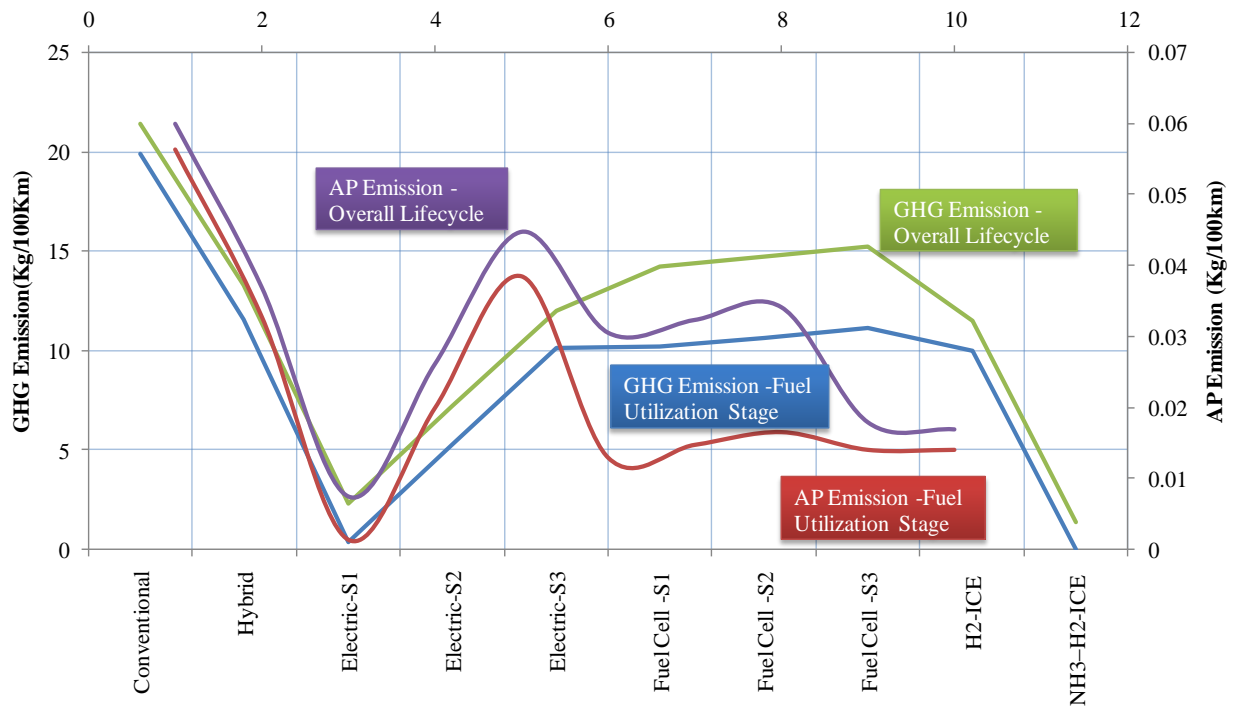


Figure1: Environmental indicators for six vehicle types [1]

Results of technical–economical–environmental Analysis:

In present situation this case study provides a general approach for assessing the combined technical–economical–environmental benefits of transportation options.

This analysis showed that the hybrid and electric cars have advantages over the others. The economics and environmental impact associated with use of an electric car depends significantly on the source of the electricity:

- If electricity is generated from renewable energy sources, the electric car is advantageous to the hybrid vehicle.
- If the electricity is generated from fossil fuels, the electric car remains competitive only if the electricity is generated onboard.
- If the electricity is generated with an efficiency of 50–60% by a gas turbine engine connected to a high-capacity battery and electric motor, the electric car is superior in many respects.
- For electricity-generation scenarios 2 and 3, using ammonia as a means to store hydrogen onboard a vehicle is the best option among those analyzed (as shown in figure 2).

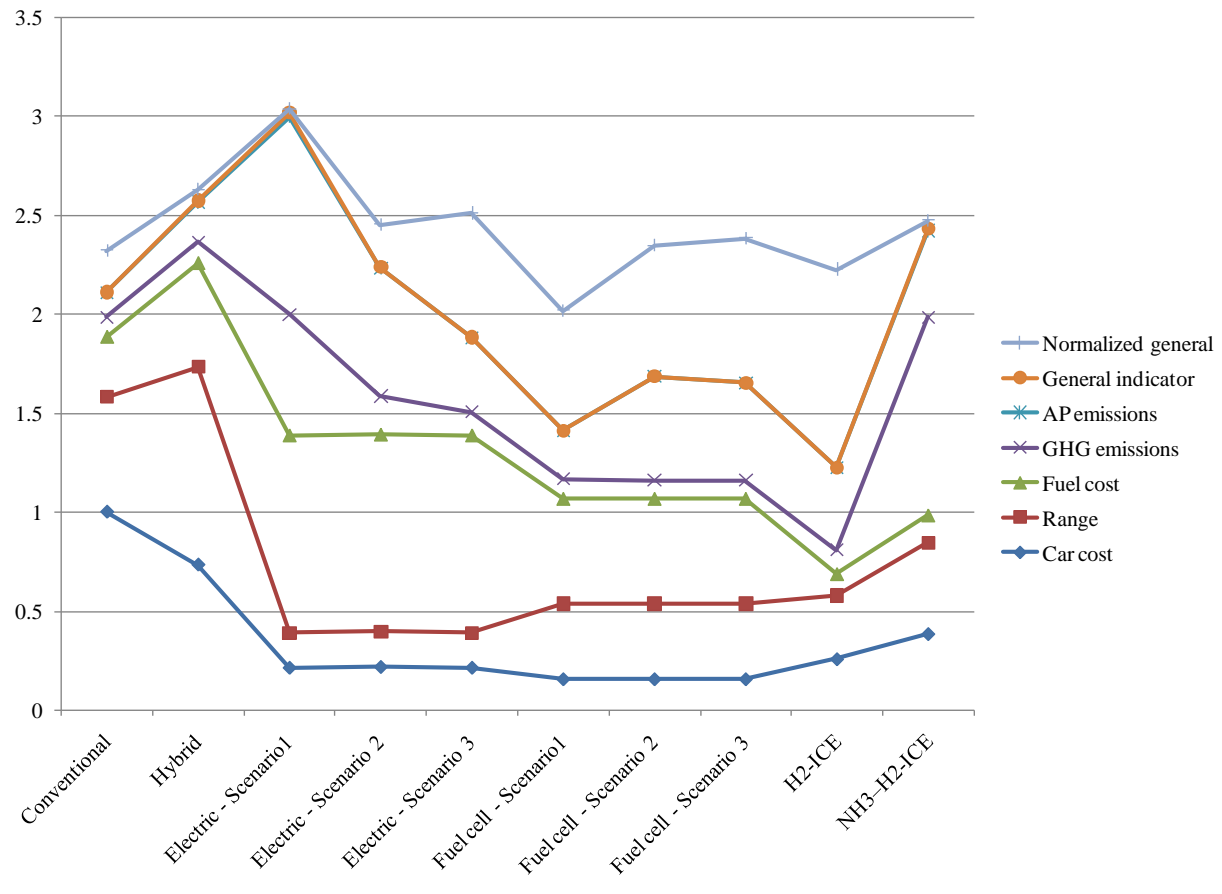


Figure2: Normalized economic and environmental indicators for six vehicle types [1]

The electric car with capability for onboard electricity generation represents a beneficial option and is worthy of further investigation, as part of efforts to develop energy efficient and ecologically benign vehicles.

The main limitations of this study were as follows:

- (i) the use of data which may be of limited accuracy in some instances;
- (ii) the subjectivity of the indicators chosen; and
- (iii) the simplicity of the procedure used for developing the general indicator without using unique weighting coefficients.

Despite these limitations, the study reflects relatively accurately and realistically the present situation and provides a general approach for assessing the combined technical–economical–environmental benefits of transportation options.

References:

[1] Gianfranco, *Electric and Hybrid Vehicles: POWER SOURCES, MODELS, SUSTAINABILITY, INFRASTRUCTURE AND THE MARKET*, Pistoia Consultant, Rome, Italy, 2010