ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

ALTERNATIVE FUELS POSSIBILITY OR PARADOX

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DOI: 10.5281/zenodo.192612

ABSTRACT

Shortage of oil will be experienced by future decade's .Fossil fuels have been during mankind over the centuries and have come to a stage where they have become a resource. Mankind cannot make requirement to search for alternative energy resources to keep mankind moving. Many authors previously have discussed the importance of alternative fuels. This review presents a detailed description of harness technology, cost analysis and advantage of alternative fuels like bio diesels, Hydrogen energy driven vehicle etc. adopting alternative energy sources will be beneficial for mankind and also will protect environment as these release less pollutants in comparison to conventional fuels. . Compared with transitional fuel, alternative fuels have superiority in environment impact, sustainability and energy efficiency. Some of them have been used in reality and shown the potential for future fuel. Electricity can also become a future fuel in mid-term period since it has excellent emission performance and low running costs. Hydrogen is expected to substitute conversional fuels in the long term due to high investment costs and current unsustainable production pathway of the latter. The compressed air turned out not suitable for substituting conventional fuels because of poor efficiency and running range performance.

KEYWORDS: Fossil fuels, Hydrogen energy, Biodiesel, Electric design, Vehicles.

INTRODUCTION

Energy consumption has been increasing continually since the urbanization. Energy demand rises worldwide, due to the growth in global population, and the fast development of transportation. Transport is the largest consumer of world oil. About 60% of oil production is used for transportation. It is also the second largest emitter of greenhouse gas. [1]About 20% of CO_2 emissions are from the transportation. The energy use of the majority of the world is based on fossil fuels. For instance, 96% of the transportation depends on oil or other oil products in India. In 2010, India imported 210 billion euro oil [2]. However oil will experience shortage in future decades, supplies are uncertain and unstable. Furthermore, oil production only occurs in some regions. In 2030 OPEC will account for 70% of liquid oil supply and 45% of total market. Thus the depletion of oil or any policy change of the oil supply could cause huge influence in energy security. Since the energy crises, energy securities start to be coincided worldwide as to become energy independent, development of alternative energies has becomes policy of many counties [3]. The internal combustion engines of vehicles emit lots of pollutants like hydrocarbons, nitrogen oxides, carbon monoxide and carbon dioxide which can lead to cancer, acid rain, heart disease and global warming, respectively. In 2009, transport accounted for 25% energy-related carbon dioxide emission [4]. In addition, half of these emission are produced by passenger vehicles. India has called for international cooperation to limit the global temperature increase to no more than 2 ºC. In order to achieve that goal, EU needs to reduce % of GHGs by 60% by 2050, in comparison to 1990 level [3]. The most promising way is making use of alternative fuel vehicle.

A change for alternative energy for future cars can be a vital option for achieving sustainable development goals. Cars which use alternative energy are called alternative fuel vehicles. Alternative fuel vehicle refers to not using traditional fossil fuels like gasoline and diesel. The conventional fuels are able to substitute by other types of energy resource, such as electric, hydrogen, bio-fuel, natural gas and etc.

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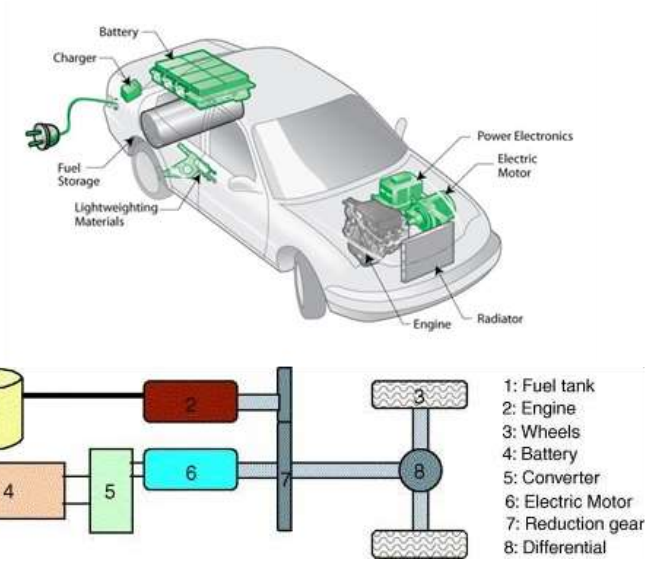
REVIEW OF VEHICLE FUELS

Conventional fuels for vehicles include gasoline and diesel. 80% of cars in the cities have an energy efficiency of 15%, which means that of a 60 L fuel tank only 9 L is useful while 51 L transfers into heat and pollutants. The emissions of conventional fuels consist e.g. of NOx, COx, SOx, hydrocarbon, VOC (Volatile Organic Compound) and PM (Particulate Matter). The CO_2 emission of conventional car is varying with type of technology and power level. In 2012 the average CO_2 emissions of conventional car is 120 g/km. Diesel and gasoline have volumetric energy densities of 35 MJ/L and 32 MJ/L respectively [4].

Electric:

Electricity is a potential fuel source for transportation. Electric vehicles (EVs) can reduce GHGs emission and dependence of traditional fossil fuel. Electric vehicles are driven by electricity power. BP forecast electric vehicle will count 8% of automobile sales in 2030 [5]. The energy of battery electric vehicle is stored in the batteries or other type energy storage device. Most of EV uses electricity motor as engine to drive directly which could achieve higher energy economy than thermal vehicles on well to wheel basis. The electricity power storage is the main technology difficulty.

Various types of batteries have been used in electric vehicles. For instance lead-acid, NiCd, nickel metal hydride, Li-ion, Li-poly and zinc-air batteries. Now Li-ion based battery become most popular for current highway-speed electricity vehicle design. That because lithium battery has relative higher power and energy density [6]. Power chain of battery electricity vehicle consists of a battery, electric motor, electric converter and wheel. Another major part of electricity vehicle is energy recovery, which could convert the waste kinetic energy to electricity while braking. Hybrid electricity vehicle is a kind electric vehicle which also contains a combustion engine. It can shut down the internal combustion engine and only use electricity motor when necessary.



1. The drive train of hybrid electric vehicle [40]

Air pollution and Environment impact:

The emission of pure electric vehicle in tail pipe is zero. Thus, city air quality will be benefited from electricity automobile. Compared with petrol vehicle, electric vehicle is the most effective technology for cutting CO_2 on a per kilo meter basis. According to the International Energy Agency, EVs are able to achieve 50 g/km CO_2 on well to wheel basis. While today's most efficient gasoline car emits CO_2 100 g/km [7].

The ability of electric vehicles to reduce greenhouse gases depends on the kind of electricity power plant. If the electricity generation is coal based, EV will create CO_2 200 g/km. This makes electric vehicles not excellent anymore when compared to conventional vehicles.[8].

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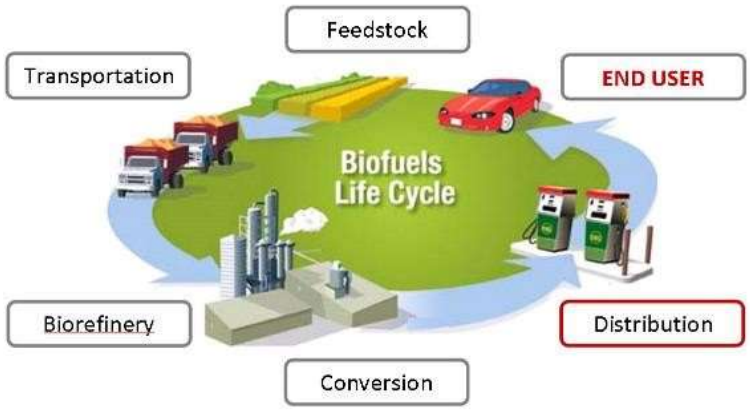
Table 1CO2 emissions per unit of energy generated at different kinds of power plants (41)

	Co_2 Emissions g/kWh	g/MJ
Coal	960	3456
Fuel oil	720	2592
Natural gas	480	1728
Nuclear	6	21.6
Hydraulic	4	14.4
Wind	3-22	10-79.2
Photo Voltaic	50-150	186-540

Energy efficiency:
Conventional internal combustion engines are inefficient. In the combustion process, majority of energy is wasted as heat. Therefore, internal combustion engine has only 15-20% efficiency. However, electricity cars are driven by electric motor which do not waste energy neither in running nor at stop. Furthermore, the waste energy during breaking can be captured by a breaking regenerating system. Hence EVs have higher energy efficiency of 80% [9]. The electricity grid is also a benefit by electric vehicles. EV can recharge at night. Thus the surplus energy of power plant in the low demand time can be fully utilized. It makes large contribution to economic efficiency of power plants.

Running costs
The cost of recharge electricity for electric vehicle is much lower than conventional vehicle due to the high efficiency drive. For instance electricity price for household consumers is 4.27 Rs/Kwh, and the fuel economy for a battery electric vehicle (Tesla Model S) is 24 Kwh/100km. So the cost for 100 km drive is 102 Rupees. However, the same size and power petrol vehicle spends 7L/100km, and the average petrol price in India is 61.09 Rupees/L. Thus the fuel cost for 100 km is approximately 427 rupees.

Biofuels:
Biofuel is a kind of sustainable energy which is derive from biomass such as sugar, crops, and animal's fat or other agricultural product. Owning to the wide spread of biomass in the world, biomass is a promising energy source. Biofuel becomes popular because of the rise in oil price and energy security requirements. World biofuel production rose from 16 billion litters to 100 billion litters in the last 15 years. Still, today biofuel only takes 3% of total transport fuel (appendix1). But IEA predict in year 2050 biofuel will offer 27% global transport fuel [10]. The biofuel cycle is showed in this Figure. First deliver biomass to the refinery. By thermal or biological method biomass can be converted to energy.



3. Biofuels life cycle [42]

First generation biofuels
Biofuels can be classified into many types. First generation biofuels – also called conventional biofuels –includes Ethanol, Biodiesel, Biogas and etc. Ethanol has been used since 1970, now it is a widely used vehicle fuel. It can be produced by ethanol fermentation: $C_6H_{12}O_6 = 2\ C_2H_5OH + 2\ CO_2$. In 2011 world production of ethanol was 84.6 billion litters which is 4 times that of biodiesel [11]. The energy density of ethanol is 66% of that of gasoline.

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However, the thermal efficiency of ethanol vehicle is higher because of the higher engine's compression ratio. Ethanol is often blended with gasoline before use. For instance, E85 means blends with 85% ethanol and 25% gasoline. [12] Ethanol is mainly produced from sugar crop. Thus it is quite sensitive to feedstock price. Appendix 3 indicates the price relation between sugar and ethanol. Biodiesel is a quilt common biofuel produced by soybean, sunflower, animal fat and used cooking oil. People are more interested in use vegetable oil for generating biodiesel owning to less pollution and renewability. Diesel combustion engine has higher efficiency, 44%, compared with the best gasoline engine, 30%. Therefore it makes diesel engine achieved more fuel economy. Beside this biodiesel mixed with normal diesel in any ratio is able to use the traditional diesel engine without modification [13]. Biodiesel often blends with normal diesel which uses "B" to indicate the biodiesel ratio. For instance B20 means blend with 20% biodiesel. On the other hand current biofuel mainly made from food product soybean, hence conventional biofuels price is also sensitive to feedstock price. However extract biodiesel from animal fat and restaurant waste oil often contain free fatty acid which made fuel not purified.

Biogas is produced by the breakdown of organic matter in lack of oxygen. Organic waste, sewage sludge and animal manure could be the raw material of biogas. Biogas mainly contains methane, hydrogen, and carbon monoxide. It can be used in many fields such as heating, cooking, electricity generating and transporting. Biogas is also able to generate natural gas after purification [13].Methanol is normally made from natural gas or coal but it can also be generated from biomass. Compared with ethanol, methanol is easier to produce and less expensive. However methanol is more toxic and absorbs water vapour more easily from air. Another promising alternative fuel is Dimethyl Ether (CH_3OCH_3) which can be produce from a variety sources such as natural gas, coal, and biomass. Diesel and petrol engine can compatible with it after modification. Dimethyl ether is sulphur free fuel and emits less NOx and CO [14].

4. First generation and second generation biofuel

SECOND GENERATION BIOFUELS

Second generation biofuels also named advanced biofuels are manufactured from lingo-cellulosic biomass agricultural residues or waste. Compared with petrol, 60% to 90% GHG can be reduced by using advanced biofuel. Second generation biofuels developed because of the limitation of first generation biofuels. Most traditional biofuels are extracted from food crop. It will however lead to competition with food which deeply influences food supplies and security. Additionally, greenhouse gas is produced while people create new farm land to grow crops. Second generation biofuels can deal with these troubles since they are more environmental friendly and sustainable. For these, advanced technology uses cellulosic materials which are not food based. Every coin has two sides. Advanced biofuels is hard to extract and not widely commercialized at present [15].

Environmental impact

Biofuel contributes to energy diversity and shares 3% of transport fuel market currently. The environmental benefits of biofuel are highly debated. Most traditional biofuels do not show the significant advantage with GHG emission except biodiesel. The CO_2, NOx and VOC emissions are not significantly changed between ethanol and gasoline. And ethanol emits little more CO than gasoline. Biodiesel contain no sulphur, hence it could help reduce the acid rain and other relative impact. Compared with normal diesel, biodiesel emits more NOx but less PM [16] [17]. Since first generation biofuel production is crop based that needs large quantities of agricultural land. Life cycle analysis indicates that first generation biofuel may lead to soil erosion, food shortage, and negative impact

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

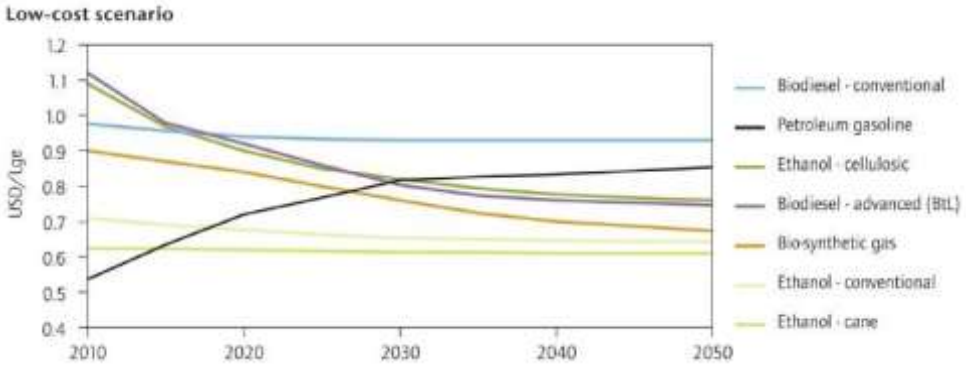
of water resource. Second generation biofuel, on the other hand, can make use of the waste biomass and not take many land space. Therefore second generation is recommended to substitute first generation biofuel [18].

Energy content

Biofuel has relative lower energy density compared with petrol. For instance, energy density of ethanol and gasoline is 25 MJ/L and 32MJ/L respectively. Biodiesels has a heating value of 37MJ/kg, which is lower than normal diesel, 45MJ/kg. Biofuel should have lower price to achieve same fuel economy with petrol [19].

Running costs

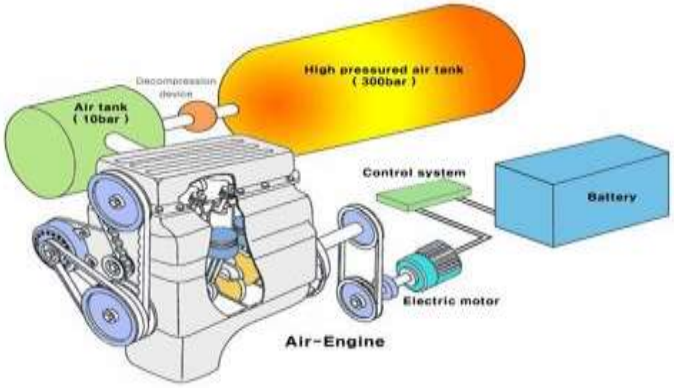
Biofuel vehicle price is moderate and competitive to conventional vehicle, but biofuel price is influenced by feed stock market, and raw material price counts 45%-70% of production cost. Price of traditional biofuel is not competitive with petrol on worldwide scale. More over advance biofuel costs even 35%-50% more than conventional biofuel [20]. (Appendix 2) indicates production costs of biofuels versus oil-based transport fuels). At present biofuel need governmental support to become price competitive. First generation biofuel has been commercialized but advanced biofuel has just reached the early commercial stage. International energy agency estimate in low-cost situation biofuel will cost parity with petrol in the year 2030 with the technical innovations and massive production. Beside this, biofuel will grow fast in the next decades and share 7% of road transport fuel in 2030, Fig.5 shows estimated trends of biofuel price.



5. Estimated biofuel prices from 2010 to 2050[20]

Compressed air:

Compressed Air Vehicle (CAV) is powered by an air engine. The compressed air is stored in a storage tank with high pressure. When air expands, the potential energy is converted to kinetic energy and finally drives the engine. The principle of compressed air vehicle is similar to that of electricity vehicle. Compressed air vehicle use air to store energy while electric vehicle use batteries. The engine releases just air as exhaust gas. No pollution will be released at the tail pipe. On the other side, fuel storage is a barrier currently. Compressed air vehicle only has about 46 km running range, because of limited volume of tank and low energy density. Furthermore, the energy storage efficiency of compressed air vehicle is much lower than traditional vehicle. Because refilling is not an isothermal process, some energy will be lost as heat. The pump to wheel efficiency of compressed air vehicle is 15%, i.e. even lower than that of advanced gasoline vehicles [21] [22].



6. Drive train of compressed air engine [43]

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Environmental impact:
As other combustion free vehicle, the pollution from exhaust gas can be largely reduced. However electricity compressor will consume lots of energy while filling the vehicle tank. Finally in the pump to wheel basis, compressed air automobile emit 1.6-2.5 times

Table 2. CO_2 than conventional vehicle and 4 times than electricity vehicle. The compressed air vehicle performance as table shows. [21]

	Compressed air vehicle	Urban gasoline vehicle	Urban electric vehicle
Fuel type	Compressed	Gasoline	Battery
Fuel Economy	38 MPG-e	32 MPG	163 MPG-e
Urban range	29 mi	408 mi	127 mi
Co_2 Emissions ($Co_{2/ml}$)	721 g	276 g	169 g
Fuel cost (Rupees)	0.36/ml	0.61/ml	0.0427/ml

Energy density and cost
Energy density of compressed air automobile is 50Wh/l which is significantly lower than that of petrol. As a result, compressed air vehicles are poor at running range. Running cost of compressed air automobile is also not cheap. This makes compressed air vehicles hard to meet requirement of normal use at present [21].

NATURAL GAS

Natural gas is fossil fuel based energy which is unsustainable but can be used to substitute petrol. It is a hydrocarbon gas which mix with methane (main contaminant), carbon dioxide, and nitrogen. Natural gas can be found in underground coal bed or oilfield and often used for heating, cooking, and generating electricity. Natural gas vehicle use natural gas major in two forms: one is Liquefied Natural Gas (LNG), and Compressed Natural Gas (CNG). Compressed natural gas is lighter than air which store with high pressure about 20-32MPa [23]. It is considered to be safer than petrol vehicles because natural gas is lighter and easy release. In addition, compressed natural gas vehicles are more commonly used for light duty vehicles.

Liquefied natural gas has double energy density than compressed natural gas which store in specially designed tanks with cool temperature -165 and low pressures (70-150 psi) [24]. It usually uses for heavy duty vehicles. Due to the higher energy density of LNG, refuelling is relatively cheaper which need hundred times less electric power compare with CNG. Benefits of using natural gas include: improve air quality; enhance energy security, lower operating costs and reduced city noise. It is world recognized one of best alternative fuel vehicles. Although natural gas is non-renewable energy, several technologies of producing bio-natural gas has been developed.

Such as biogas, bio methane and bio-synthetic gas which is able to collect from organic waste. In addition, fuel distribution, transmission grid, fuel storage and fuel refilling could limit natural gas vehicle development [25]. Natural gas price is influence by the transmission, development of network and distribution. The competitiveness of natural gas is higher where there is a high level of infrastructure development. Natural gas vehicle experience a fast growing in recent decade: from 1 million in 2000 to 11 million in 2009. The technology of natural gas vehicle cover all kinds of automobile from motorcycle to truck. As fig. shows, the share of natural gas is expected to increase dramatically until 2030. It will represent more than 10% of future alternative fuels and play an important role in the short term for substituting petrol [26].

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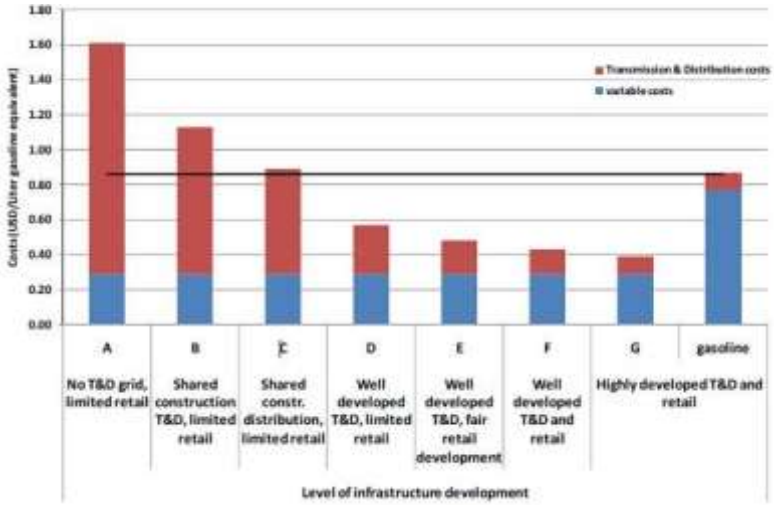
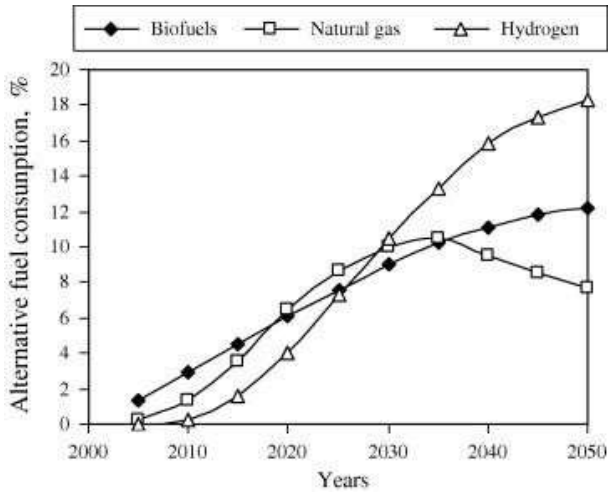
Storage tank of natural gas vehicle [44]



7. Costs of CNG in different grid development condition [25]



8. Estimated shares of alternative fuels of total vehicle fuel in future [45]

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Air pollution and Environmental impact

Natural gas is regarded as the cleanest fossil fuel. In well-to-wheel analysis, natural gas emits 25% less carbon dioxide than gasoline for producing same amount of heat. This is due to the fact that natural gas has lowest CO2 /energy ratio. Natural gas also emits less SO2, NO2 and PM than other hydrocarbon based fuels [25].

Energy content

The energy density of natural gas is lower than regular fuel. Energy content of LNG and CNG is 25MJ/L and 9MJ/L, i.e. 60 and 25 percent of diesel fuel, respectively. So natural gas vehicle needs larger space for fuel tank [25].

Running costs

A variety of natural gas vehicles is available on the market such as Volkswagen, Fiat, Benz, Citroen, Peugeot, Volvo, and Renault and so on. The technology of natural gas vehicle is mature and affordable. Based on the report of International Gas Union, in 2009 retail price difference between natural gas and petrol for medium size light duty vehicle is EUR 2520. With the technology developing cost of fuel storage have been acceptable. Gasoline car can be modified to CNG vehicle as old tank kept. The US department of energy says: cost of modification is about 6000 dollar for regular vehicle [25].

Country / Region	Diesel(USD/lge)	Petrol(USD/lge)	CNG(USD/lge)
OECD Europe	1.32	1.39	0.74
OECD North America	0.57	0.59	0.30
OECD Asia	1.39	1.70	0.62
Argentina	0.56	0.63	0.26
Bangladesh	0.42	0.67	0.22
Brazil	0.89	1.25	0.77
China	0.62	0.77	0.42
Egypt	0.19	0.16	0.07
India	**0.65**	**1.04**	**0.33**
Iran	0.01	0.10	0.04
Malaysia	0.57	0.63	0.22
Pakistan	0.70	0.93	0.49

Natural gas price can be influence by petroleum price. But historically, mean price of natural gas has was more stable than petrol. In recent years natural gas become much lower than gasoline which makes operating cost reduce. According to UK National Society for Clean Air and Environmental Protection Organization says cost of using natural gas is 20%-60% lower than gasoline and 20%-40% lower than diesel. The retail prices of natural gas normally lower than gasoline which is variable between different countries. Table.4 compares the end user price in 2009 for fuel in different country [25].

Hydrogen

Hydrogen can be used as source of power for vehicles, and it is a clean energy carrier. The Hydrogen vehicle converts chemical energy to kinetic energy in an environment friendly way. Hydrogen can be generated form variety of source and widely distribute. Hydrogen powered vehicles majorly are classified into two types [26]:

1. Hydrogen Internal Combustion Engine Vehicle (HICEV)
2. Fuel Cell Vehicle (FCV).

Hydrogen internal combustion engine vehicle is similar to regular petrol engine. As traditional engine does, hydrogen fuel reacts with air in the combustion process but final production is water.

$2H_2 + O_2 = 2H_2O$

Therefore it is considered as zero emission in tail pipe. In order to store hydrogen with high density, hydrogen vehicle has a high pressure tank. Compared with the petrol internal combustion engine, efficiency of hydrogen internal combustion engine is almost same which about 0.2-0.3. Fuel cell vehicle use fuel cell to generate electricity for the electric motor, through fuel and oxygen chemical reaction. Fuel cell vehicle produce few

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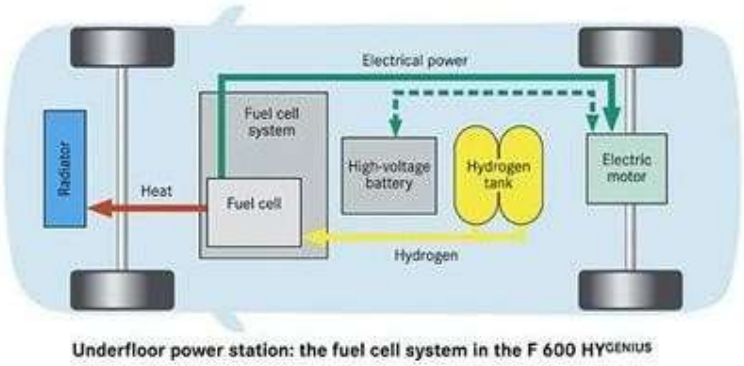
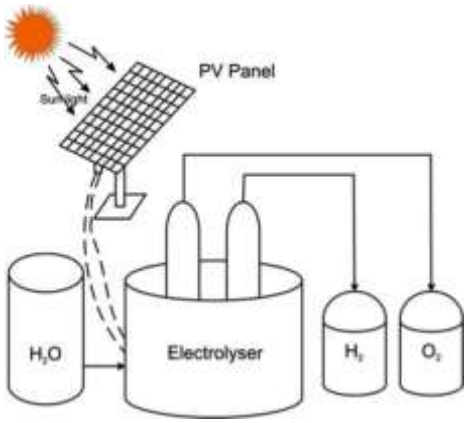
pollutants, majority in water and heat. It can achieve 0.4-0.6 efficiency which is higher than internal combustion pathway [27].



8. Mercedes-Benzes fuel cell vehicle F600 drive chain [46]

However, there are some barriers for hydrogen fuels develop. Firstly, generation of hydrogen may have some negative impact to environment. In world, 95% of hydrogen production is made from methane, and 48% came from natural gas reforming in traditional way. Common methods of producing hydrogen from fossil fuel based energy source include: Steam Reforming Process, Partial Oxidation Process and Auto thermal Reforming Process [28]. Currently small amounts of hydrogen are produced from renewable energy resources, for instance solar and bio hydrogen producing pathway. In solar–hydrogen scenario, initially solar energy is converted to electric energy. Then hydrogen is created by electrolysis of water. Apart from this, biomass and wind energy are also suitable for producing hydrogen.



9. Photovoltaic hydrogen production system [47]

In the renewable generation method there is no direct fossil consumption and also has less energy security impact, however currently it is still costly and has slow production speed. Secondly, infrastructure for hydrogen transformation, refuel station, pipeline for deliver, refuel station is lacked at present. So hydrogen may not play an important role before 2020, but will probably be a vital technology in the long term period [29].

Air pollution and Environmental impact

A benefit of using hydrogen vehicles is low tailpipe pollutions. Hydrogen powered vehicles is a nearly zero-emission vehicle. But traditional method to converter hydrogen would cause environment consequence as greenhouse gas emission. Therefore the advantage of hydrogen fuel is not significant if hydrogen is produced traditional way. At present, new production pathways for hydrogen are still in small range. Fig. shows the emission performance of different pathway [30].

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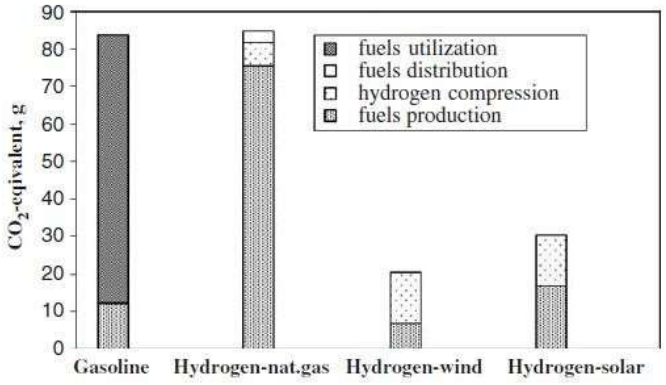


10. Greenhouse gas emissions of produce and utilize 1MJ gasoline or hydrogen (31)

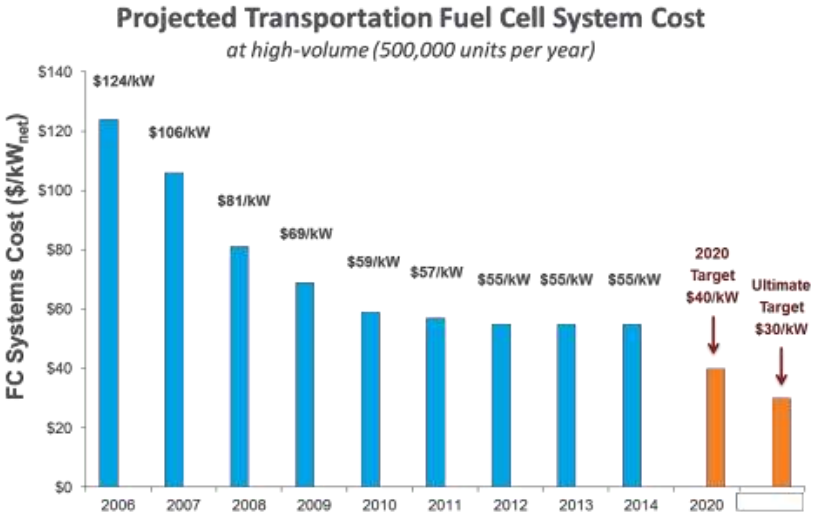
Energy content

Compared with energy density of petrol (32MJ/L), the energy density of hydrogen is quite low which only 5.6MJ/L for compressed hydrogen and 8.5MJ/L for liquid hydrogen. As a result it a special storage system to keep requires hydrogen in greater density and meet high pressure and low temperature demand [31].

Running costs

Currently hydrogen vehicles cost is higher than regular fuel vehicle. Hydrogen internal combustion vehicles are not produced massively. Although a few of hydrogen internal combustion vehicle has produced for demonstration. On the other hand, several of fuel cell vehicles have come to commercial these years. Toyota announced that their fuel cell hydrogen vehicle will sale for 60,000 EUR in 2015. Figure below make a compare with hydrogen and other same size vehicle (1 mile = 1.6 km, mpg-e: mile per gallon equivalence).

Hydrogen price is sensitive to other fuel price. In 2007 cost of hydrogen production is 50 USD/GJ and in next decade it expects drop to 10-15 /GJ. Furthermore, depending on different raw material productions, cost is also not same. Non fossil fuel based pathway of generating hydrogen is presently not economical. Production hydrogen from solar–hydrogen pathway may be 5 times more expensive than produce hydrogen from coal. Appendix 4 presents the cost of produce hydrogen in different method. Thirdly, the hydrogen recharge infrastructure could be another barrier because it will add extra cost. Large amount of distribution pipe network and refuel station will add 4-11USD/GJ hydrogen to cost [32]. Lastly, fuel cell vehicle must become affordable in order to replace conventional vehicle. From last decade full cell price was falling fast. US Energy Department is planning to have fuel cell price decline to USD 40/kW in 2020.



11. Predicted fuel cell cost from 2006 to 2020 [48]

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Liquefied petroleum gas

Liquefied petroleum gas (LPG) also called auto gas is a wildly used alternative fuel which mainly consist of butane (C_4H_{10}) and propane (C_3H_8). It can be used for heating, cooking, refrigeration and transport fuel which currently drive from crude oil or natural gas. In 2008 there were 14.8 million vehicles using LPG as fuel. LPG has high octane value of 105 compare with normal gasoline 95 that make it suitable for internal combustion engine. Gasoline vehicle is able to run with auto gas by retrofitting a high pressure tank (760-1030kPa). The tank will store liquefied petroleum gas is made form with low temperature [33]. Although liquefied petroleum gas make from unsustainable source energy, the energy security of liquefied petroleum gas is equal with biodiesel and higher than CNG [34]. Furthermore technology of producing LPG through biomass has been developed. It may increase the sustainability of LPG.

Table 3. Emissions of LPG compare with other fuel (g/km) [23]

	THC	NMHC	CO	NO_X	PM
Gasoline	0.08	0.07	0.06	0.03-0.08	0.01
Diesel	0.06	0.06	0.05	0.03-0.05	0.04
Diesel with PM filter	0.01	0.01	0.01	0.03-0.05	0.02
CNG	o.15	0.30	0.30	0.03-0.06	<0.001
Auto Gas	0.05	N.A	0.30	0.05-0.08	<0.001

Air pollution and Environmental impact

Liquefied petroleum gas is considered to have potential in releasing less CO, PM, NOx and VOC by many researchers [36]. Particle emission with LPG is ten times less than burn diesel [34]. The CO_2 emission performance of LPG vehicle is almost same level of petrol vehicle today.

Energy content and Running costs

Energy density of LPG is 26MJ/L which is lower than gasoline. In addition energy efficiency of auto gas vehicle is 10-15% lower than that of diesel vehicles. Hence auto gas vehicle consumes about 35-50% more fuel than diesel vehicle [37]. However the cost of running LPG vehicle is lower than petrol due to the competitive price of fuel. For instance the average auto gas price in Europe is only half of petrol [38].

DISCUSSION

Every coin has two sides. Various alternative fuels have their advantage and disadvantages. Most alternative fuels have better emission performance. Some of them have been commercially used. Below is a summary of different kinds of alternative vehicle fuels used, as well as their advantages and disadvantages, sustainability, energy density, cost, production and emission performance.

Energy density comparison

Fuels have various kinds of property parameters such as energy content, heating value, energy density and so on. Energy density refers to the amount of energy storage per unit volume. The space for storing fuel in vehicles is limited; therefore the running range of vehicle is largely depended on energy density. Due to this, energy density was chosen for comparing the running range of vehicles

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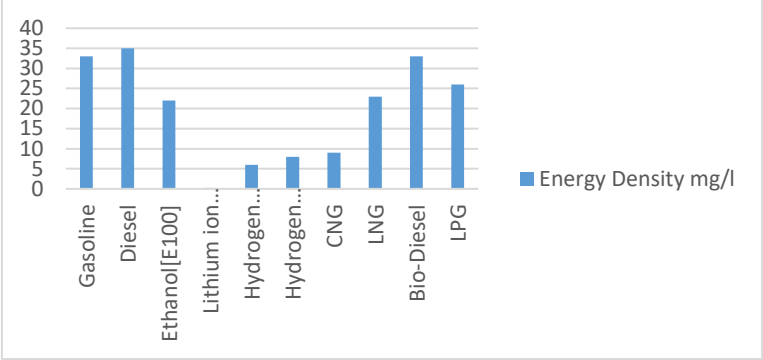

As the figure shows, energy density of each fuel is difference. Diesel has highest energy density (35MJ/L) and compressed air is the lowest (0.2MJ/L). Therefor compressed air vehicle need more space to store fuel or increase the times for recharge. However there is one thing different: run range for the electricity vehicle is not as small as the picture indicates. This because efficiency of electricity motor is higher than 80%, compare with internal combustion engine 15%-20%.

Properties of alternative fuels

Table 4. Properties of different fuels [30]

	Chemical Structure	Source	Physical State	Sustainability	Running Cost	Investment cost
Biofuel Bio diesel Biofuel Ethanol E100	Methyl, ethyl C2H5OH	Fats and oils from plants sugar crop	Liquid Liquid	Renewable	high high	medium medium
LNG CNG	CH4 CH4	Underground reserves Underground reserves	Cryogenic liquid Compressed Gas	Unsustainable Advantage produce method renewable	low low	medium medium
Electric Li-ion battery	Lithium-ion	Coal, nuclear, natural gas, hydropower, wind, solar, biofuel	Electricity	Renewable widely spread	low	high
Hydrogen	H2	Natural gas, electrolysis water, Biomass	Cryogenic liquid	Advantage produce method renewable	low	high
LPG	C4H10 C3H8	Crude oil, natural gas	Liquid	Unsustainable Advantage produce method renewable	low	medium

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Compressed air	air	air	Compressed Gas	Use electricity to Compresses air	medium	–
Gasoline	hydrocarbon	Crude oil	Liquid	Unsustainable	medium	medium

Various properties of fuels are compared in the above Table. Gasoline is considered as a reference in the table. Compressed Natural Gas has been used for long time which technology is stable. It was regarded as cleanest fossil fuel with good emission performance. Natural gas price is lower and relatively stable than petrol and positive to energy security. However now a days most of compressed natural gas is produced from unsustainable sources and not widely distributed.

Electric vehicle has zero emission which has lower fuel consumption cost. It can become short and medium term solution for substituting petrol vehicle. A number of electric vehicles have come to market and they will play an optimal role for the urban transportation []. The sustainability of electricity vehicle depends on the pathway of electricity generation. But investment cost of electric vehicle is still at high level. With the mass produce of battery, investment price is expected to drop. Hydrogen is also a good alternative fuel because of the emission performance. Barrier of hydrogen fuel include hydrogen production and infrastructure distribution. The traditional hydrogen generation pathway is unsustainable, and advanced methods unable to meet the demand. Hydrogen has lower energy density that need special tank to store fuel. Furthermore hydrogen powered vehicle cost is higher which make it less attractive to market.

Currently, there are many countries using biofuel automobile. Biofuel can be produced from renewable resource which contributes to energy diversity. The IEA predict the share of biofuel for road transport fuel will goes to 7%, and will continues increase to 27% in 2050. [39] Hence biofuel will play a vital role for substituting the conventional fuel in short and medium term. There are several limitations for biofuel. First generation biofuel mainly extract from crop which highly relate to feed stock price. That makes the price of biofuel unstable and sensitive. Besides this, widely produced conventional biofuel may threaten the food security. Second generation biofuel seems a hopeful pathway to deal with these issues.

Compressed air vehicle still need technical renovation to meet the demand in mileage. Use air as fuel is sustainable. At the same time lower energy density, storage difficultly and energy consumed refilling limited the growing of compressed air vehicle. The importance of the use of renewable energy sources for vehicle fuels is obvious. But the possibilities for alternative energies to substitute conventional fossil fuel highly depend on current technology and cost. Some fuels are unable to use for substitution at present although they have better environment performance. Moreover, the growing of the alternative fuel vehicle market can be effected by government policies, such as develop related infrastructure, creation of alternative fuel friendly tax system, investment in R&D and international collaboration.

CONCLUSIONS

Historically, conventional fossil fuels have been used for vehicles for long time, but the decline of available fossil fuels drives the exploration of alternative energies. Alternative fuels provide ways to shift energy consumption to less carbon, low pollution and more energy diversity. Compared with transitional fuel, alternative fuels have superiority in environment impact, sustainability and energy efficiency. Some of them have been used in reality and shown the potential for future fuel.

Compressed natural gas and liquefied petroleum gas have been used for a long time. The technology of them is mature and reliable. Good emission performance and relatively low operating costs decide these kinds of fuels have high possibilities to be used for substitution energy in short term period.

Electric vehicles emit few emissions and the technology has developed dramatically in recent years. But infrastructure construction and the price affect popularization of electric cars. With mass production, price of electricity vehicle will become more competitive. It is a promising pathway to substitute gasoline vehicle where electricity generated from renewable source in mid-term period.

Biofuel is another potential fuel for future vehicle in short-term and mid-term. In order to produce biofuel more environmentally, however, current production methods need to be more advanced.

Currently, hydrogen is not suitable for substituting traditional fossil fuels although it has excellent emission performance. Hydrogen running cost is lower but most hydrogen production is fossil fuel based at present. It is however a promising alternative fuel in the long term. Also compressed air vehicles are not yet suitable as an alternative fuel. Technology limits in fuel storage, refill procedure, vehicle running range and production cost make compressed air vehicles hard to be accepted by market.

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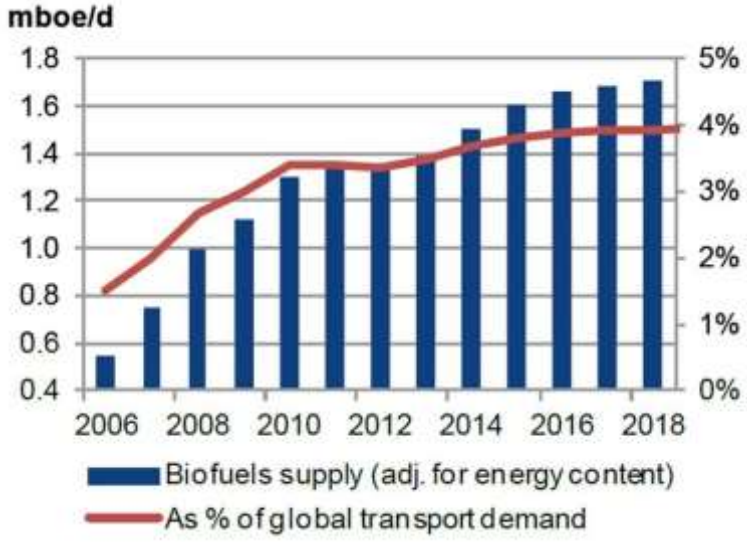
Appendix:

Appendix 1

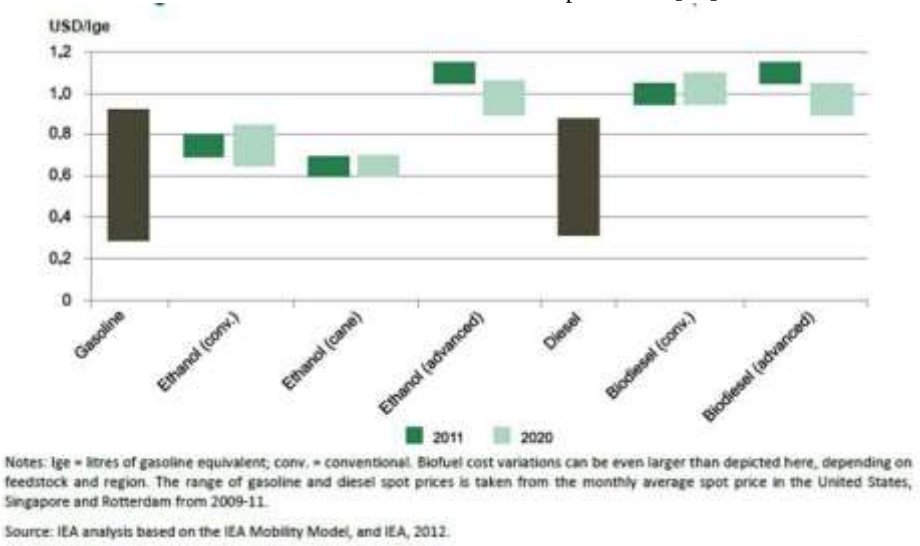
Global biofuels supply from 2006-2018 [24]



1 b/d=58,030,255liters
1boe=240 litres of ethanol; 180 litres of biodiesel

Appendix 2

Production costs of biofuels versus oil-based transport fuels [24]



Notes: lge = litres of gasoline equivalent; conv. = conventional. Biofuel cost variations can be even larger than depicted here, depending on feedstock and region. The range of gasoline and diesel spot prices is taken from the monthly average spot price in the United States, Singapore and Rotterdam from 2009-11.

Source: IEA analysis based on the IEA Mobility Model, and IEA, 2012.

Appendix 3

Sugar price versus hydrous price, Brazil ethanol price [24]

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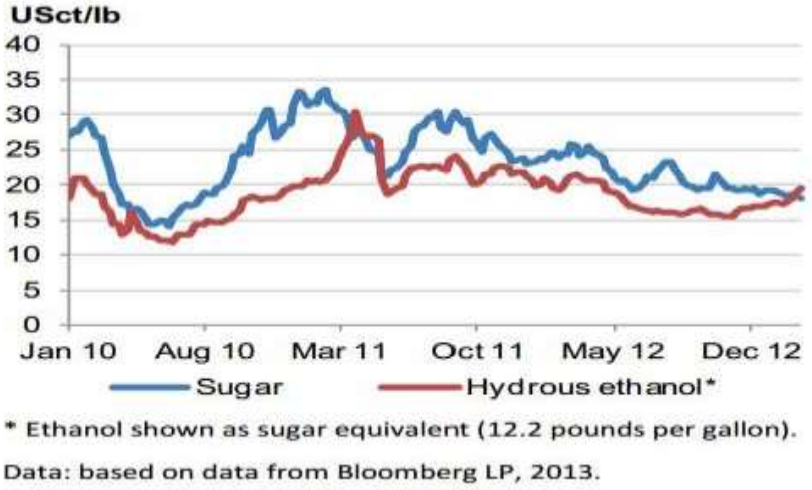
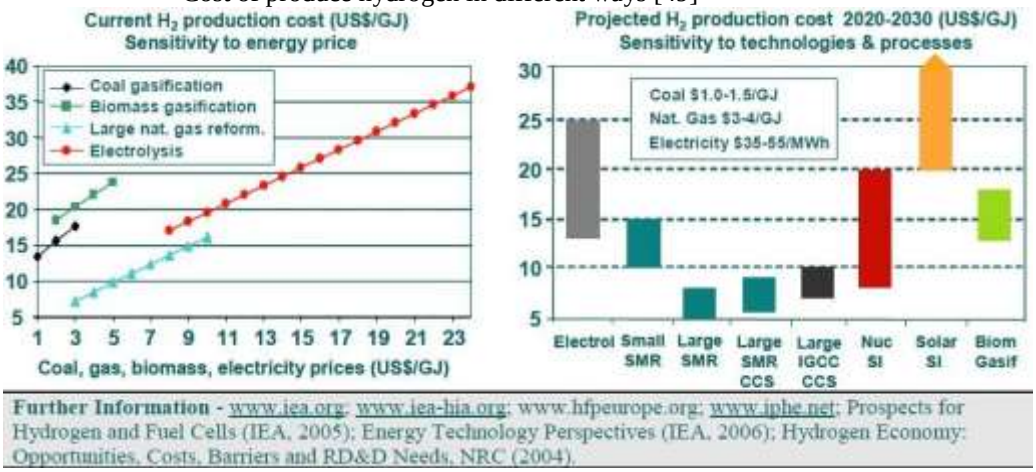


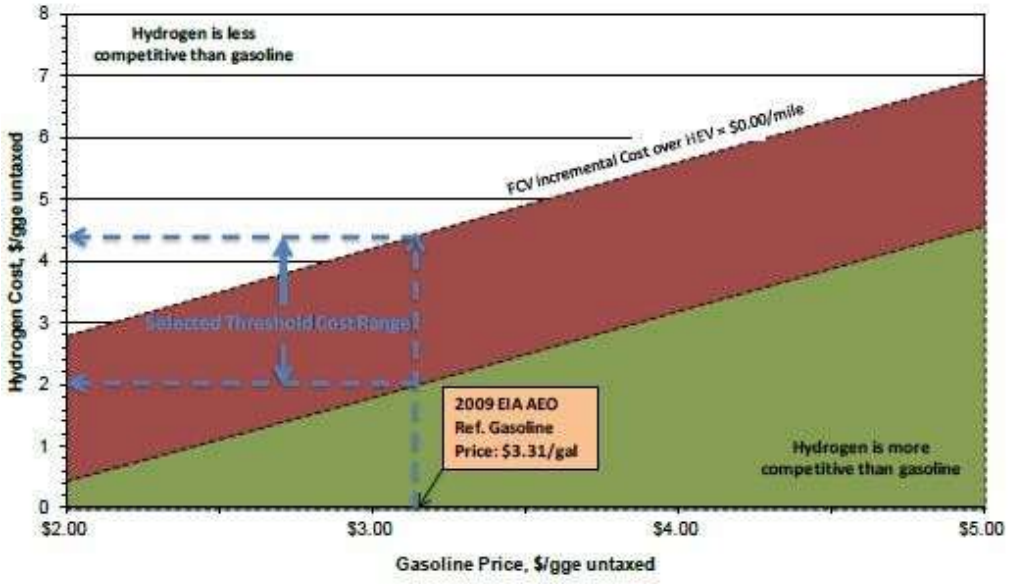
First generation biofuel price is sensitive to feedstock

Appendix 4

Cost of produce hydrogen in different ways [49]



Hydrogen price in order to competitive with gasoline [49]



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GGE: Gasoline gallon equivalent
1 gallon gasoline has 33.41 kWh energy
1GJ = 3,600,000,000 kWh
8.31 USD/GGE = 1 USD/G

Abbreviations
GHG: Green House Gas
OPEC: Organization of Petroleum Exporting Countries
BP: British Petroleum
VOC: Volatile Organic Compound
PM: Particulate Matter
EV: Electric vehicle
IEA: International Energy Agency
LNG: Liquefied Natural Gas
CNG: Compressed Natural Gas
HICEV: Hydrogen Internal Combustion Engine Vehicle
FCV: Fuel Cell Vehicle
LPG: Liquefied petroleum gas
CAV: Compressed Air Vehicle