Life Cycle Cost (LCC) Analysis: Hydrogen as an Alternative Fuel for Internal Combustion Engine (H_2ICE)

H. Razali, B. Ali, S. Mat, A. Zaharim and K. Sopian

Abstract**—**Estimate the Life cycle cost (LCC) for the internal combustion engine (H_2ICE) that use hydrogen as an alternative is to forecast a financial investment plan for a period of in years (n) and are influenced by interest rates (i). Affect of Annual Operating Cost and salvage value in the plan LCC for H2ICE much to give the impact on the cost of investment and economic growth in the long term plan. The operation of H_2ICE at the first year will be increased by + 22%, the reason is due to the cost of equipment purchases, maintenance and purchase of new components. The percentage of operation cost for the next year for Present worth (PW) dropped to 0.36% in the fourth year (n = 4) within interest rates of 10%. Return on initial investment in capital-First cost (FC) to occur at the beginning of the fifth year (n = 5) H2ICE operations, and for the next five years the cost of savings become more profitable with reaching - 37% reduction in cost compared to fuel consumption conventional.

Keywords**—**Life cycle cost (LCC), Hydrogen, Internal combustion engine, engineering economic, alternative fuel.

I. Introduction

DEVELOPMENT and modification of the conventional engine (petrol) to H2ICE is part of the development of Green Car Technology (GCT), using alternative fuels, otherwise use ethanol, biodiesel, LPG, and the NGV. Changes in the use of hydrogen as a fuel through a chemical reaction process by acid (HCl) and aluminum an efficient method for generating hydrogen and cheaper to apply and diversity in the use of hydrogen in ICE is an advantage to this study, namely through the choice of 100% use of hydrogen as a fuel, or by a mixture of hydrogen equal to or less than 15% with petrol into the combustion chamber. The different of engine performance can be accessed through the achievement of engine parameters such as engine power (Pe), torque (T), horsepower (ip), fuel consumption (SFC) and pollution (HC, CO2, NOx) before and after modification. So the writing of Life Cycle Cost (LCC) for this project to help design and analyze H_2ICE project in the long term by studying the behavior of its effectiveness, when the project in the marketing eventually and equivalent to the financial provisions provided.

To evaluate the LCC development in this study, is a step in structuring the investment cost needs, including the evaluation of the choice of technical equipment which is subject to the requirements of a project H2ICE. Referring to Figure 1, the planning of development of the LCC study consisted of two parts, first; Engineering Financial Economy (Institution)-this section aims to evaluate the investment in the development of First cost (FC), Annual operating cost (AOC), salvage value (SV), and life in year (n), and second; Technical equipments - this part of the basics of drafting technical requirements in terms of the Cost of acquisition, Maintenance, Conversion and Decommission. From the Cost of acquisition section, it is divided into three basic stages of restructuring in the design of the LCC H_2ICE requirements include the following activities: Research Development - This unit aims to restructure the management programs that involve technical, R & D, the process of designing, manufacture of components and also conducted technical tests of the decision to be an important references in the development project, it is called as engineering data.

The second stage, Non-Recurrent investment cost - This division is the process of economic plan that do not involve the production of recurring investments such as planning for development of spare parts and logistics, manufacturing, operations and maintenance, preparation of project development facilities , training and testing data during the as a reference for improving the quality assurance (QA). and the third stage; Recurrent investment cost - this part to covers the activities to upgrade technical equipment related (Up-grade parts), providing support equipment, creating a repair system integration, provides utility improvement costs, and inventory to the development of equipment to the project or the concept of green technology (H. Paul Barrainger 2003, Leland T. Blank & Anthony J. Tarquin -3ed 1989, Faisal I.Khan et.al 2005).

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H. Razali, B. Ali, S. Mat, A. Zaharim and K.Sopian is with the Solar Energy Research Institute, Universiti Kebangsaan Malaysia, 43600 Bangi Selangor, MALAYSIA.

(E-mail: razalihalim@yahoo.com, azami.zaharim@gmail.com, ksopian@eng.ukm.my)

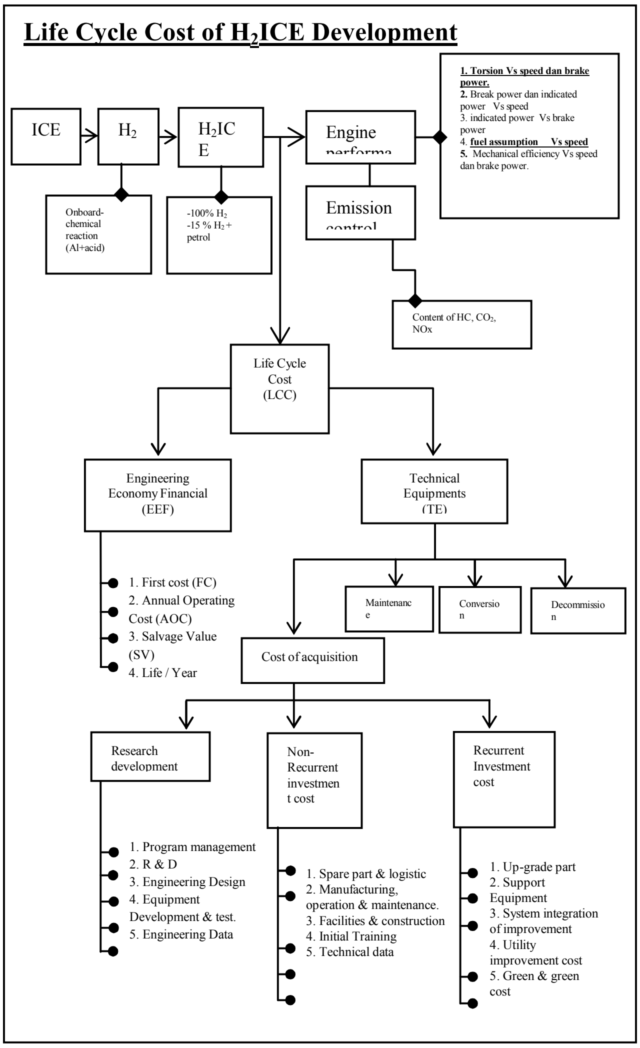

Fig. 1: The structure flow of Life Cycle Cost (LCC) for H2ICE development plan

II. Estimate the Annual operating costs (AOC) using petrol as fuel for the next five and ten years

Based on the findings of the data obtained as shown in Table 1, showing the experimental assessment of resource needs petrol RON 97 types of daily activities using the conventional fuels, and the Table 2 is an analysis of information from Table 1 that displays an estimate of the cost of using petrol as fuel for a motorcycle vehicles. The experiment activity for using petrol within full-scale filling a tank is 2.78 liters, and the price of fueling current valuable (RON 97) is RM 2.50 per liter, this is activity for a period of one month is estimated by an average of four times, and the total of filling is 8647 liters with cost is RM 21.63 sen and the distance of journey can be achieve is around 36.51 km. Within a year the total expenditure of money required is estimated at RM 259.56 cents for 438.12 km distance of journey, and the forecast for five year period the reached 2196.6 km journey, and the cost of petrol increased up to RM 1297.80 cents, and when the activity reached the level of ten years, the cost of purchase increase of RM 2595.60 cents with the travel distances to 4381.2 km. This paper showing how to calculation will change if global fuel prices increased or decreased and is impacted from the current global fuel market.

Table 1 The collection of data fuel consumption (RON97) for motorcycle Modenas Kris 110, four strokes

RM 2.50/LITER	REFILL /RM	LITER /TANK	KM	RM/KM
	6.76	2.703	10.46	0.65
1 MONTH	5.41	2.162	10.92	0.49
	4.05	1.620	7.47	0.54
	5.41	2.162	8.12	0.67
	4.05	1.620	8.70	0.47
2 MONTH	4.05	1.620	7.47	0.54
	6.76	2.703	10.54	0.64
	4.05	1.620	7.45	0.54
	4.05	1.620	5.66	0.72
TOTAL:	**44.58**	**17.83**	**76.79**	**5.26**
AVERAGE:	**5.21**	**2.08**	**9.10**	**0.57**

Table 2 Analysis of AOC in RM 2.50/km for the current prices of petrol (RON 97)

AOC		RM/1M	RM/1Y	RM/5Y	RM/10Y
FRQ	RM/LITER	1M	12M	60M	120M
	6.76	21.63	**259.56**	1297.80	2595.60
1M	5.41				
	4.05				
	5.41				
TOTAL	RM 21.63	36.51 KM	**438.12 KM**	2196.6 KM	4381.2 KM

III. Estimate the Annual operating costs (AOC) using Hydrogen as fuel for the next five and ten years

The outline of the requirements of hydrogen-based fuel sources in this study is referring on a few important facts of the previous studies such as Kunio Uehara (2002), Wang HZ (2009) and F. Franzoni (2009) as shown in Table 3. According to Kunio Uehara in the study stated, the vehicle hydrogen can be moving as far as 250 km, requires 2 kg of hydrogen with 18 kg of aluminum is used as a process generated from the chemical activity. While opinions HZ Wang wrote in his study, a total of 4 kg of hydrogen necessary to move as far as 400 km for the type of fuel cell vehicles. And researcher F. Franzoni in the study obtained with 1 kg of aluminum is able to produce around 112 grams of hydrogen generated from the oxidation of aluminum at a temperature of 298K. Based on this information, all three of the basic calculations can theoretically be produced to estimate the needs of the use of hydrogen to travel in distance of miles, and requirements of aluminum for generating hydrogen and the cost needs to adopt hydrogen as an alternative compared to petrol. The expected cost of the daily requirements includes requirements within one year, five years and ten years as showing in Table 2.

Table 3: The findings of the needs of the aluminum to generate hydrogen in the chemical activity

RESEARCHER/YEAR	AL/KG	H2/GRAM	KM
H.Z WANG (2009)	-	4000	400
KUNIO UEHARA (2002)	18	2000	250
F.FRANZONI (2009)	1	112	-

A. The theoretical computation for the hydrogen estimate based on distance needed

The computation of the theoretical estimate for the hydrogen needed via programs that use Microsoft Office Excel-formula as the basis for the development of forecast for annual operating cost based on the engineering economic. This calculation aims to estimate the generation of hydrogen process in accordance with the distance of miles. It serves as a manual for the daily consumers purpose (H2EPD) to generate hydrogen via aluminum and acid generation. There are three requirements for the LCC estimate; Necessity of hydrogen based on distance of miles, Necessity of aluminium based on weight of gram and the current cost of hydrogen application based on mixture scale.

B. Necessity of hydrogen based on distance of miles.

To determine the need for hydrogen in kilograms by the distance of travel miles can be evaluated to determine the need for annual operating cost (AOC). Referring to the Table 4, the AOC needs (H2ICE) in the year showed the average of number of trips km (Motorcycle) is around 438 km (Table 2), and requires 3.5 kg of aluminum to produce hydrogen as a fuel H2ICE, this is result finding via to study results Kunio Uehara (2002), stating the total travel distance of 250km requires 2000 grams of hydrogen.

C. Necessity of aluminium based on weight of gram

The amount of aluminum per gram needed to produce hydrogen can be determined by mathematical calculations as shown in Table 4 below, according to the needs of 3,504kg of hydrogen, the required amount of aluminum is 31.29 kg this is according to F. Franzoni (2009) states, one kilogram of aluminum capable of producing hydrogen at 112 grams.

Table 4: Hydrogen and aluminium requirements based on mileage.

ESTIMATE/ITEM	SKALA	REFERENCE
HYDROGEN ESTIMATE		
H2/GRAM	**2000**	*KUNIO*
KM (REFERENCE)	**250**	*UEHARA (2002)*
KM/YEAR	438	TABLE 2
HYDROGEN REQUIREMENT/KG	3.504	
ALUMINIUM ESTIMATE		
AL/GRAM	**1000**	*F.FRANZONI*
H2/GRAM	**112.00**	*(2009)*
HYDROGEN REQUIREMENT/KG	3.504	
ALUMINUM	31.29	

REQUIREMENT/KG

D. The current cost of hydrogen application based on mixture scale.

The cost of the use of hydrogen with mixture scale is 1:1(1 kg: 1 liter HCl) and the final stage of the computation associated with the affair of 3.2) and 3.3), to determine the total cost of the use of aluminum / kg and acid hydrochloride / liter to produce the 3.504 kg of hydrogen to travel as far as 438 km. Refer the Table 5, showing the requirements of 31.29 kg aluminum, with acid hydrochloride 31.28 liters. Current cost of the two basic ingredients of this is RM 125.14 (aluminum) plus with RM 20.65 (HCl) and total amount of money only RM 145.75 is required to travel as far as 438 km, and the overall of cost of hydrogen compared within gasoline for in few year are shown in Table 6.

Table 5. The AOC cost of the use of hydrogen and Al mixture to scale of 1 kg: 1 liter HCl

AOC OF HYDROGEN	PRICE
CURRENT PRICE	
ALUMINIUM 1KG/RM	4.00
ACID(HCL) LITER/RM	1.32
TOTAL DISTANCE KM/ 1 YEAR	
DISTANCE IN KM	438
ALUMINIUM	
AL KG /KM	31.29
AL RM/KG	125.14
ACID HYDROCHLORIDE	
HCL LITER/KM	31.285
HCL RM/LITER	20.65
TOTAL RM/KM	
TOTAL AL + HCL, RM/KM	**RM145.79**

Table 6. Comparison of the overall cost of hydrogen compared with petrol base on operation in one year.

BASIC MATERIALS (H_2)	QUANTITY FOR 438 KM/YEAR	TOTAL RM /YEAR
AOC OF H_2ICE		
1. ALUMINIUM	31.29 KG	RM 125.14
2. ACID HYDROCHLORIDE	31.285 LITER	RM 20.65
AOC OF PETROL		
PETROL (RM 2.50/LITER)	102.2 LITER	RM 259.56

IV. THE COST OF MAINTENANCE AND REPLACEMENT OF COMPONENTS H2ICE FOR THE PERIOD BETWEEN FIVE AND TEN YEARS.

Sort ways of planning for the annual maintenance activities divided into three categories: Normal service, Major Service and Replaces parts. The schedules of maintenance have the gap of time three months for each of the categories of repair performed. The scope of the basic maintenance can be divided into three parts: The internal combustion engine, CCH, and support components, the maintenance activities have been organized according the sensitivity of a component, and priorities situation such as event of any damage and need to be replaced. All annual maintenance cost for the LCC plan for Hydrogen fuel sources and petrol are facilitated to reference on Table 7.

Table 7. Summary of the costs maintenance from Table 8 for LCC plan in between Hydrogen and petrol.

ESTIMATED COST (1YEAR)	H_2ICE	ICE(PETROL)
1. FIRST COST –FC	RM 5400.00	RM 5400.00
2. REPLACEMENT COST	RM 195.00	RM 95.00
3. ANNUAL COST OF MAINTENANCE	RM 60.00	RM 40.00
4. LIFE / YEAR	1	1
5. TOTAL ANNUAL COST	**RM 145.79**	**RM 259.56**

V. ANALYSIS OF THE EXPENDITURE COST FOR THE TWO OPTION ALTERNATIVES (H2 VS PETROL) AT THE SAME YEAR PERIOD OF OPERATION.

This section is an important procedure in the initial LCC analysis of a project involving a financial investment for a period of time and investors make money through the difference in annual operating cost, salvage value and interest rates (i) the operation of a project. Annual assessment period for this project is five years (n = 5) and ten years (n = 10) operated by the interest rate (i) at 10%.

Refer to Table 8, to describe the overall of life cycle cost (LCC) for the use of hydrogen to compare with petrol for internal combustion engines (H2EPD) during the time period of 10 years of operation within the interest annually rate is 10 %. In the first year operating cost of using hydrogen (H2ICE) compared with gasoline rose to +22%, is due to the CCH system acquisition, maintenance and spare parts for the purpose of shifting to alternative fuel sources. In subsequent years the cost of operating expenses decreased by 16% until the fourth year (n = 4) 0.36%. and the return of capital for the purchase of motorcycles and CCH system is expected to occur in year five (n = 5) because the AOC for H2ICE value spending is more economical than AOC for petrol powered engines. Savings in expenditure will reach up to -37% when n = 10, although only operate with the par five-year difference in returns from investments beginning occur.

Table 8: The total summary of LCC result for investment costs planning H2ICE for 5 years and 10 years

PW/YEAR	H_2ICE	ICE PETROL	RESULT
N = 1	RM 7101.35	RM 5513.22	$P_{H2} > P_{PETROL}$
N = 2	RM 7284.54	RM 6077.00	$P_{H2} > P_{PETROL}$
N = 3	RM 7712.91	RM 7032.15	$P_{H2} > P_{PETROL}$
N = 4	RM 8351.84	RM 8322.19	$P_{H2} > P_{PETROL}$
N = 5	RM 9171.55	RM 9900.45	$\mathbf{P_{H2} < P_{PETROL}}$
N=10	RM 15,177.37	RM 20,832.81	$\mathbf{P_{H2} < P_{PETROL}}$

VI. CONCLUSION

The effectiveness of CCH system in terms of engineering economy for internal combustion engines has been proved via calculation of LCC, which takes into account current costs, such as First cost (FC), Annual operating cost (AOC), salvage value (SV), and the number of years it operated (life in year-n). Effectiveness of H2ICE can be seen mainly through the difference in annual operating costs is low and minimum maintenance is one of the advantages. Apart from the profit in terms of improved engine performance, control of pollution, hydrogen also provides a more effective economic return compared to petrol, petrol prices due to market uncertainty in the global market until on this day.

REFERENCES

[1] H Paul Barringer (2003). A life cycle cost summary. international conference of maintenance societies (ICOMS-2003). Perth. Western Australia.

[2] Leland T. Blank, A. J. T. (1989). Engineering Economy third edition, Mcgraw-hill Book compony.

[3] Faisal I.Khan, K. H., M.T. Iqbal (2005). "Life cycle Analysis of win-fuel cell integrated system." Renewable Energy **30(2005)**: 157-177.

[4] Kunio Uehara, H. T., Hiromi Kotaka, (2002). "Hydrogen gas generation in the wet cutting of aluminium and its alloys." Journal of Materials processing technology **127(2002)**: 174-177.

[5] H.Z Wang, D. Y. C. L., M.K.H Leung, M.Ni (2009). "A review on hydrogen production using aluminium and aluminium alloys." Renewable and Sustainable Energy Review **13(2009)**.

[6] Federica Franzoni, M. M., Luca Montorsi, Valeri Golovitchev, (2010). "Combined hydrogen production and power generation from aluminium combustion with water: Analysis of the concept." Internasional Journal of hydrogen energy **35(2010)**: 1548-1559.