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Fuel Options for Vehicles in Korea and Role of Nuclear Energy

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1. Introduction

Nowadays, almost all vehicles in Korea are powered by gasoline or diesel and they are emitting about 25% of nationwide total carbon dioxide emission. With jetting up price of oil and concerns about global warming by use of fossil fuel, transition to the hydrogen economy gains more and more interest. As alternatives to the current fossil powered vehicles, hybrid, hydrogen, electricity powered vehicles are considered. In short term we will reduce dependence upon fossil fuel by using hybrid cars. However, in the long term, we have to escape from the dependence on fossil fuel. In this context, nuclear-driven hydrogen or electricity powered cars are the alternatives.

In this study, we estimated the operation cost of cars powered by hydrogen and electricity from nuclear power and studied about the major blocks on the way to independence from fossil fuels. In the analysis, we put the capital cost of car aside.

2. Gasoline Powered Vehicle

One measure of the performance of a supply chain is its energy efficiency. For vehicles, such a measure is the well-to-wheels calculation of the amount of energy used per kilometers driven. Gas mileage of medium size sedans in Korea is about 12 km/l. And the gas price is bouncing around 1.5 \$/l. Then the dolor mileage of the passenger car is 0.124 \$/km.

$$M_{Gasoline} = 0.124 \ \text{[\$/km]} \tag{1}$$

And because the heating value of gasoline is 32 MJ/kg, the energy mileage of that car is about 2.67 MJ/km. If we assume the efficiency of internal combustion engine is 20%, the actual mechanical energy mileage of that car is 0.53 MJ/km.

3. Hydrogen Powered Vehicle

There are three major ways to produce hydrogen. Steam methane reforming (SMR), electrolysis of water or steam, and thermo-chemical water splitting. Nuclear can contribute to electrolysis and thermo-chemical water splitting. In maturity of hydrogen production technology, electrolysis has greatest advantage on thermo-chemical methods which is under development along with development of hi temperature nuclear reactors.

We can use electricity from nuclear power plant to produce hydrogen, and hydrogen price would be the sum of electricity price and capital cost of hydrogen production plant:

$$C_{Electrolysis} = C_{Electricity} + C_{Capital} \ \text{[\$/MJ]} \tag{2}$$

The capital cost of electrolysis plant mainly comes from the cost of electrolyzer. Because the electrolyzer is the reverse use of fuel cell technology, the cost of electrolyzer is equal to the cost of fuel cells. The current price of fuel cell is under 2000 \$/kW [1]. If we assume the capital cost of electrolysis plant per unit kW of hydrogen production is:

$$C_{Capital} = \frac{C_{FC}[\$/kW]3.6[MJ/kWhr]}{\eta_{Electrolyser}\eta_{capacity}T_{plant\ life}[hr]} \ \text{[\$/MJ]} \tag{3}$$

And the electricity cost is:

$$C_{Electricity} = \frac{C_{\$/kWh}Q_{LHV}[MJ/kg]}{3.6[MJ/kWhr]\eta_{electrolyzer}Q_{HHV}[MJ/kg]} \ \text{[\$/MJ]} \tag{4}$$

Then the dolor mileage of hydrogen car is:

$$M_{H2} = \frac{C_{Electrolysis}[\$/MJ]0.53[MJ/km]}{\eta_{FC}\eta_{Motor}} \ \text{[\$/km]} \tag{5}$$

4. Electricity Powered Vehicle

If we use rechargeable battery for powering vehicles, we can just consider electricity cost.

$$M_{Electricity} = \frac{C_{\$/kWhr}0.53[MJ/km]}{3.6[MJ/kWhr]\eta_{Charging}\eta_{motor}} \ \text{[\$/km]} \tag{6}$$

All the variables used in above calculation is listed in the Table 1.

5. Results and Discussion

We have estimated the dolor mileage of gasoline, hydrogen, and electricity powered vehicles. Electricity cost was varied from 0.05 to 0.12 \$/kWhr. The average retail price of electricity in Korea is around 0.075 \$/kWhr.

As shown in the Fig. 1, the operating cost of gasoline car is the highest among three options followed by hydrogen car and electricity car. When the cost of electricity reaches 0.12 \$/kWhr, the operating cost of gasoline and hydrogen powered car have the same operating cost. Considering the operating cost only, the electricity powered car is the best options can replace fossil powered car. And using the hydrogen from nuclear-produced electricity is not the bad potion in terms of operating cost. The current electricity price is around 0.07\$/MWhr. Even considering tax on hydrogen from nuclear electricity, hydrogen has the same degree of compatibility with gasoline.

Table 1. Variables

Variable	Value	Unit
Electricity cost, $C_{\$/kWhr}$	0.05-0.12	\$/kWhr
Electrolyzer efficiency, $\eta_{Electrolyzer}$	0.5	-
Low Heating Value, LHV	120	MJ/kg
High Heating Value, HHV	142	MJ/kg
Efficiency of IC engine	0.2	-
Efficiency of fuel cell	0.5	-
Efficiency of DC motor	0.95	-
Fuel cell price	2000	\$/kW
Electrolyzer life time, $T_{plant\ life}$	5	Years
Capacity factor of H_2 plant, $\eta_{Capacity}$	0.8	-

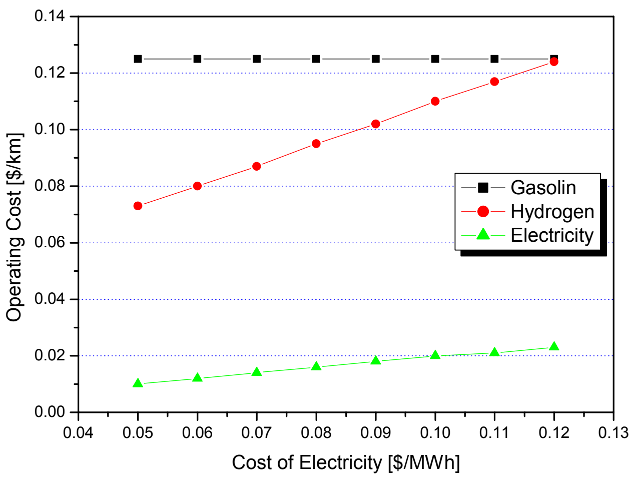

Figure 1. Operating cost of three vehicles

However, hydrogen or electricity powered cars have considerable cost of car itself. The major block on the way to hydrogen car is fuel cell price not the hydrogen price itself. The hydrogen fuel itself costs not much compared to the current gasoline price. Mass production of hydrogen at the level of current gasoline price is possible and affordable using electricity from water cooled reactors in Korea. The efforts to develop high temperature nuclear reactors for hydrogen production have been being made. To make the high temperature reactor viable in near future, it is very important to take down the fuel cell price and to make hydrogen use get grow by making hydrogen using current nuclear reactors.

The gasoline used in transportation in Korea during last year (2004) was 60,000,000 bbl. It is equivalent to $2.6X10^{11}$ MJ. Assuming 20 % of efficiency of internal combustion engine the total mechanical energy used is $5.2X10^{10}$MJ. If we supply that energy by electricity and assuming 20% of charging loss, 5% of motor loss, and 90% of capacity factor, 2.4 units of 1,000 MWe grade nuclear power plants are needed in Korea. The capital cost of electric car is 5,000 to 10,000 \$ higher than gasoline car. In this range, the initial capital cost can be made up due to its very low operating cost (1/10 of gasoline car, see Fig. 1).

5. Conclusions

Considering operating cost of the hydrogen and electricity powered vehicle, electric car appears to be the best option for replacing fossil fueled vehicles, and hydrogen car can be another option.

But the cost of hydrogen car is very high to compete with gasoline car. Therefore the emphasis should be on developing advanced fuel cell.

The cost of electric car is moderate and its operating cost is ten times lower than gasoline car. Therefore the electric car can be near term alternative and the hydrogen car can be long term one after considerable efforts are poured onto fuel cell development.

In summary, nuclear energy can make contribution in replacing fossil fueled car by hydrogen production using electricity (hydrogen car) or by electricity itself (electric car). And, even though the hydrogen from fossil fuel is cheaper than that from nuclear, the initial hydrogen feed stock can be supplied by using water cooled nuclear reactors running well without any green house gases.

REFERENCES

1. Haruki Tsuchiya and Osamu Kobayashi, Fuel Cell Cost Study by Learning Curve, International Energy Workshop, Stanford University, USA, 18-20 June 2002.