Eco-efficiency measurement for Hydrogen as an alternative public transportation fuel

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Abstract

This study aims to identify the environmental and economic aspects of hydrogen pathways as an alternative public transportation fuel using the concept of Eco-efficienc which is estimated using life cycle assessment (LCA) and life cycle costing (LCC) methodologies. The target H_2 pathways are made up of naphtha steam reforming (Naphtha SR), natural gas steam reforming (NG SR), and water electrolysis (WE). Additionally, conventional fuels (Diesel and CNG) are also included as target fuel pathways in order to identify which hydrogen pathway in particular the greatest eco-efficiency over the conventional fuels. Global warming (GW) impact is studied to examine the environmental aspect of each target fuels. And the life cycle costs of target fuels are computed and several key factors are examined to identify the economical feasibilities of target systems. Given that H_2 technologies and infrastructures have yet to be fully commercialized, the environmental and economical aspects of each pathway are analyzed in both their present status and a future scenario in 2015.

The conclusion to be drawn here is that H_2 pathways, especially, Naphtha SR and NG SR, have a competitiveness compared with conventional fuels from an eco-efficient aspect. As a result, the substitution from conventional transportation fuels to H_2 pathways is expected to offer a sustainable means of public transportation. Henceforth, drawing upon evidence within this study, decision-makers would be wise to invest in more cost-effective and environment-friendly fuels by constructing sustainable public transportation systems.

Keywords: hydrogen, CNG, Diesel, life cycle assessment, life cycle costing

1. Introduction

Since a bus as a public transportation is a main reason of various air pollution problems, such as photochemical smog, acid rain, and particulate matter, as well as the environmental and economical problems related to global warming, urban government is making an effort to improve air quality by the substitution to environmental and economical-friendly fuels. In Korea, compressed natural gas buses (CNGB) have been operating since 2000, with the aim of improvement air condition in urban area. Although CNGB can decrease some regulated air pollutants such as CO, NOx, SOx, VOC, dust, it can not in itself solve global warming problem, because it uses CNG as a fuel which is a fossil fuel. Therefore, a more robust solution is required to tackle issues about global warming and unacceptable air quality in urban area. Among many alternative energy sources, H_2 is an attractive option. H_2 can be produced from methane, gasoline, biomass, coal or water. H_2 can be produced either centrally, and then distributed, or onsite where it will be used. In addition, H_2 might serve as an environmentally cleaner way to deliver energy to end-users, particularly in transportation applications, without release of pollutants at the point of end use. The aim of this study is to identify whether H_2 and fuel cell bus (FCB) can compete with conventional fuels used in buses in terms of economic feasibility and environmental improvement through eco-efficiency.

2. Methodology

LCA is a systematic tool to analyze the environmental impact of a product throughout all stages of its life cycle - from the extraction of resources, through the production of materials, parts and the product itself, and its use to the management after it is discarded, either by reuse, recycling or final disposal. LCA compiles and evaluates the inputs and outputs and the potential environmental impacts of a product system throughout its life cycle. [1][2] This study estimated the environmental impacts based on the international standards for LCA, ISO 14040-44.

This study attempts to estimate the life cycle costs of target systems by integrating the various cost-categories such as capital costs, operational costs, and maintenance costs. In performing LCC, this study defined the total life cycle costs of the target systems as consisting of the well-to-tank (WTT) and tank-to-wheel (TTW) costs, where the former is the sum of the costs incurred from raw material extraction to the station and the latter the costs incurred from the driving of the vehicle such as vehicle purchasing costs, and fuel costs. [3][4]

3. Target fuel pathways

The target fuel pathways consist of Naphtha SR, NG SR, WE, Diesel, and CNG in this study. WE is classified WE [Korea Electricity Mix; KEM] and WE [Wind power Electricity; Wind] according to the type of generation system. Each target fuel pathway consists of six life cycle stages: raw material extraction, raw material transportation, fuel processing, fuel distribution, station (fuel compression & storage) and fuel utilization.

4. Analysis model

For comprehensive comparison of the analysis results of target fuel pathways, comparisons were made on the basis of the same function, functional unit, and reference flow between the LCA and LCC methodologies. [5] Table 1 shows function, functional unit, and reference flow used in this study.

Table 1. Function, functional unit, and reference flow for LCA and LCC

	CNG	Diesel	H_2
Function	Transportation fuel for vehicle driving		
Functional unit	Daily driving distance (257.9 km) x 365 days x 11 year ≒ 1,077,000 km driving		
Reference flow	426,300 kg	570,600 kg	109,500 kg

The present case is not enough to compare the environmental and economic aspects of conventional fuels and H_2 pathways as a public transportation fuel, so in this study, the eco-efficiencies of target fuel pathways were compared with respect to time. Thus, this study carried out future status analysis with considerations regarding market launch time of H_2 FCB and advancing of technology on H_2 production and vehicles.

5. Results

5.1 Environmental results

This study considers the global warming potential impact (GWP) as an environmental aspect. Table 2 shows the GWP results associated with the entire life cycle of the target fuel pathways in the future case. All H_2 pathways have lower GWP results than the conventional fuels. The reason for this is that H_2 pathways do not emit any GHGs during the fuel utilization stage, and have more efficient fuel economy than conventional fuels, although they emit lots of GHGs in H_2 production from steam reforming and water electrolysis. In particular, WE[Wind] has the lowest GWP results among all H_2 pathways, because it uses electricity generated by wind power to produce H_2 for the Korean electricity grid.

5.2 Economical results

Table 3 shows LCC results associated with the entire life cycle of the target fuels pathways in the future case. All H_2 pathways have lower WTT costs than the conventional fuels, because the facilities purchasing costs for H_2 production would be cut by developed technology and the effect of mass production. TTW costs of all H_2 pathways are also cut down owing to the decrease of vehicle purchasing cost by technology development. Therefore, all H_2 pathways will become cheaper than the conventional fuels by US $525,000(WE[Wind] vs diesel) ~ US $615,000 (NG SR vs diesel). In H_2 pathways, NG SR is the most competitive public transportation fuel compared with diesel, because of its cheap resource and operating costs compared with Naphtha SR and WE[KEM, Wind].

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Table 2. Environmental results

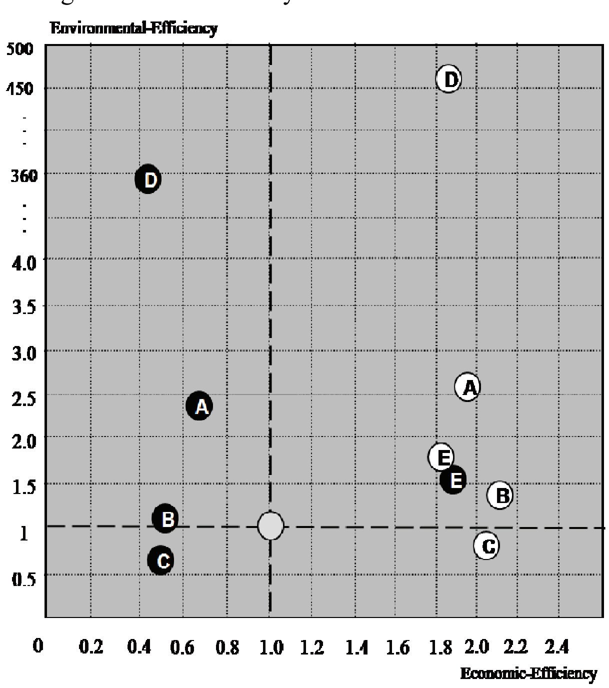
Fuel Pathway		GWP results in the future case (t CO_2 equiv.)					
		A	B	C	D	E	F
H_2	Naphtha SR	4.02E+01	3.66E+00	2.54E+02	1.16E+02	4.33E+01	-
	NG SR	1.83E+02	1.70E+01	1.12E+02	4.06E+00	5.92E+02	-
	WE[KEM]	-	-	5.62E-02	-	1.26E+03	-
	WE[Wind]	-	-	5.62E-02	-	2.00E+00	-
Conventional Fuels	CNG	4.52E+02	4.20E+01	2.80E+01	1.00E+00	1.16E+02	1.37E+03
	Diesel	1.84E+02	1.80E+01	4.90E+01	5.00E+00	6.07E-02	1.56E+03

A: Raw material extraction, B: Raw material transportation, C: Fuel processing, D: Fuel distribution, E: Station, F: Fuel utilization

Table 3. Economical results

Fuel Pathway		LCC results in the future case (US $)		
		Capital cost	Maintenance cost	Fuel cost
H_2 Fuels	Naphtha SR	387,958	54,835	202,884
	NG SR	387,958	54,835	143,509
	WE[KEM]	387,958	54,835	157,743
	WE[Wind]	387,958	54,835	232,958
Conventional Fuels	CNG	109,802	54,835	476,040
	Diesel	146,144	57,004	997,666

Figure 1. Eco-efficiency results



Fuels	Environmental-Efficiency		Economic-Efficiency	
	Present	Future	Present	Future
A: Naphtha SR (C)	2.477	2.671	0.696	1.965
B: NG SR (S)	1.145	1.360	0.532	2.125
C: WE[Mix] (S)	0.663	0.867	0.501	2.012
D: WE[Wind] (S)	357.2	471.8	0.488	1.881
E: CNG	1.683	0.619	1.889	1.871

Present : ● Future : ○ Diesel : ○

5.3 Eco-efficiency results

Figure 1 shows the results of Eco-efficiency related to the target fuel pathways in both the present case and future case. For the present case, the portfolio analysis clearly shows that Naphtha SR, NG SR, WE[KEM], and WE[Wind] have approximately the same economic efficiency results but different environmental efficiency results. While the result of Eco-efficiency show Naphtha SR, NG SR, and WE[Wind] are more competitive than diesel and CNG in terms of the global warming aspect, none of the H_2 pathways are cost-competitive with diesel and CNG due to the prohibitively high FCB purchasing cost. Therefore, it will be difficult for FCB to penetrate the market at present. For the future case, NG SR and WE[KEM] are competitive with diesel and CNG from the point of view of global warming and economic aspects. Most notably, NG SR is regarded as the best fuel supply option for future public transportation due to the high life cycle cost of WE[Wind]. Moreover, if the high life cycle cost of WE[Wind] is lowered by way of technological development in the future, it may eventually supersede NG SR as the most practical alternative fuel for public transportation. From an environmental and economic policy standpoint, it can be considered to prompt the replacement of FCB in order to reduce GHGs for compliance to the climate change convention.

6. Conclusions

The conclusion to be drawn here is that H_2 pathways, especially, Naphtha SR and NG SR, have a competitiveness compared with conventional fuels from an eco-efficient aspect. As a result, the substitution from conventional transportation fuels to H_2 pathways is expected to offer a sustainable means of public transportation. Henceforth, drawing upon evidence within this study, decision-makers would be wise to invest in more cost-effective and environment-friendly fuels by constructing sustainable public transportation systems.

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