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# Bioethanol: Is It a Suitable Biofuel for Hong Kong for Reducing Its Vehicular Emissions and Carbon Footprint?

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**Abstract**

Excessive vehicular emission is regarded as one of the main sources of air pollutants and this problem is especially serious in a metropolis such as Hong Kong. In California, legislation already exists to replace the toxic MTBE additive by an oxygenated additive such as ethanol. Many trials of testing ethanol fuel on gasoline fleet have also been conducted in many countries. In Hong Kong, the gasoline fuel practically contains no ethanol. In 2010, the Environment Bureau of the HKSAR Government has issued a climate change consultation document proposing 10% biofuels for road transport by 2020. Although the consultation document could not get through, whether Hong Kong can adopt the use of ethanol blended fuel and its environmental benefit is still an interesting and important issue in Hong Kong's environmental policy development. The purpose of this study is to evaluate the feasibility of introducing ethanol blended fuel to a metropolitan city such as Hong Kong. Implementing this policy involves a lot of difficulties related to infrastructure, taxation, acceptability of oil companies and car manufacturers, political issues etc. These issues have been addressed in this study. In addition, a life cycle analysis on the greenhouse gases emissions for different feedstock of ethanol production has been conducted to reveal the real benefit of using the fuel. Result indicated that ethanol produced locally from waste paper can generate real advantages to the Hong Kong environment and is more realistic in implementing in Hong Kong. There will be an insignificant cost penalty of 1% to 2% to motorists when using E5 and E10 respectively.


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*Keywords:* Bioethanol fuel; Life cycle analysis; LCA

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## 1. Introduction

Ethanol (normally called bioethanol) is considered to be one of the best alternative fuels and additives for spark ignition (SI) vehicles. Ethanol is a renewable fuel produced from plants while gasoline is a petroleum-based fossil fuel. The ethanol production process represents a carbon cycle, where plants absorb $CO_2$ and release it during fuel combustion. It is sold as a high-octane fuel that delivers improved vehicle performance while reducing emissions and improving air quality. Ethanol fuel is currently used in many countries such as the USA, Canada, Sweden and Brazil, and its annual consumption amounts to ~90 billion liters per year and is in a fast-growing trend.

In order to obtain early information regarding the feasibility of using more bioethanol as an auto fuel of the gasoline cars in Hong Kong, this study aims to evaluate the effects of using various ethanol blends on performance characteristics, emission behaviors, compatibility and durability issues. Furthermore, implementing a policy in Hong Kong, particularly related to fuel, will involve a series of consideration in infrastructure, taxation, acceptability of oil companies and car manufacturers, political issues and so on. These issues will be addressed in this study. It has to be mentioned that other forms of clean vehicular fuels, such as biogas and EV, are not considered in this study since it is less feasible to be adopted in Hong Kong in short to medium term.

## 2. Environmental Analysis

### *2.1. Tail Pipe Emission Test Results in Literature*

A dynamometer testing on a 4-cylinder, 4-stroke compression ratio of 9:1 at 3/4 throttle on unleaded gasoline showed that ethanol/gasoline blends was capable to improve the engine performance and at the same time obviously reduce carbon monoxide (CO) and unburned hydrocarbon (HC) emissions but with increase in carbon dioxide ($CO_2$) [1]. Changes in % blend with ethanol would affect fuel volatility and latent heat hence in turn affect charge temperature, hence volumetric efficiency, air fuel ratio and obviously heating value. E20 was shown to be the optimum blend. Poulopoulos et al.[2] compared the exhaust emissions before and after catalytic converter operations. The result demonstrated that E10 required lower engine power for higher conversions, but the behaviours of individual compounds were irregular. By means of total fuel cycle analysis, Tyson et al. [3] showed that E95 would give significantly lower emissions in CO, VOC, NOx and SOx than reformulated gasoline fuel. Graham et al. [4] found considerable variations and even contradictions in historical results due to variations in fuel quality, test vehicle conditions, engine type, fuel injection, tailpipe emission treatment designs and so on. Nevertheless, they were able to obtain statistical median of vehicle tailpipe emission changes for E10 and E85 as shown in Table 1 which indicated that there is no definite trend in the tailpipe emissions with increased ethanol blending as found by Al-Hasan [1].

Table 1. Statistical median of vehicle tailpipe emission changes for E10 and E85 [4].

| | E10 | E85 | | E10 | E85 |
|---|---|---|---|---|---|
| CO | -16% | 8% | 1,3-butadiene | 16% | -77% |
| NOx | 3% | -45% | Benzene | 15% | -76% |
| HCHO | 5% | 73% | $CO_2$ | 0.6% | Not determined |
| NMOG[1] | 14% | 5% | $CH_4$ | -9% | Not determined |
| NMHC[2] | 9% | -48% | $N_2O$ | 2% | Not determined |
| Acetaldehyde | 108% | 2540% | | | |

N.B. [1]. Non-methane Organic Gas ; [2]. Non-methane Hydrocarbon

### *2.2. Environmental Implications in the Use of Bioethanol*

The lack of a consistent trend in tailpipe emissions with increased ethanol blending is also supported by the review of the Motor Vehicle Emission Simulator (MOVES) modelling system of US Environmental Protection Agency by the National Transportation Systems Center [4]. The review indicates existence of turning points at different % ethanol blends for different pollutant emissions. However, their research has included simulations for vehicle roadside emissions in using various ethanol blending. For the present analysis, their simulated results in g/mi for passenger cars for different ethanol contents for urban unrestricted access are considered to be most pertinent to the local situation. Table 2 shows the averaged results obtained for the three fuel types (i.e. E0, E5 and E10) included in the 2014 version of MOVES for CO, $NO_2$, $NO_x$, total hydrocarbon (THC) and volatile organic compounds (VOC) which are of most concern for gasoline vehicular emissions:

Table 2. Percentage Change in Emissions for Various Ethanol Blends.

| | CO | $NO_2$ | $NO_x$ | THC | VOC |
|---|---|---|---|---|---|
| E0 | 0 | 0 | 0 | 0 | 0 |
| E5 | -2.8% | +3.7% | +3.7% | -1.5% | +0.3% |
| E10 | -5.3% | +8.0% | +8.1% | +0.6% | +4.5% |

It can be seen that except CO, there could be no benefits, or even penalties in blending gasoline with ethanol as far as urban emissions is concerned. In addition, these emission changes would have an impact on the ambient ozone levels and the consequent impact to the overall ambient air quality cannot be established without very complex analysis of the atmospheric chemistry and traffic patterns that cannot practically be included in the present study.

## 3. Environmental Life Cycle Analysis (LCA) of Bioethanol for Application in Hong Kong

The land scarcity of Hong Kong will not favour local farming to produce the relevant crops for ethanol production. However, bioethanol production from waste cellulose-containing matters is considered to be an option. The bioethanol so produced can be blended with imported gasoline and hence such option is considered in the present analysis. Bioethanol produced overseas and transported to HK is also considered in the LCA for comparison.

### *3.1. LCA of Waste Paper Based Cellulosic Feedstock*

Life cycle analysis of bioethanol produced from local waste paper/cellulose-containing matters is conducted to compare with that of the first generation feedstock. The key goal and scope assumptions are:

- Feedstock source: waste papers are collected locally and processed in a bioethanol mill;
- The functional units are kg $CO_{2\text{-eq}}$ /kg$_{\text{-ethanol}}$ and kg $CO_{2\text{-eq}}$ /km$_{\text{-end use}}$ representing the Mill-to-Station life cycle GHG emission (ethanol production) and Mill-to-Wheel life cycle GHG emission (ethanol production and end use);
- The system boundary is defined to include the waste paper Pre-processing, Bioethanol Production, Distribution and end use stages. As there is no commercial scale plant for cellulosic bioethanol conversion, the process is modified based on the US National Renewable Energy Lab process (bioethanol production from corn stover) [5];
- The inventory data for different stages are mainly depends on local transportation/ electricity generation assumptions, literature review and computer modelling, ancillary chemical and process data was obtained from built-in database in SimaPro like Ecoinvent and U.S. Life Cycle Inventory.

### *3.2. LCA results and interpretation*

Life cycle impact assessment (LCIA) was conducted using the IPCC 2013 GWP 100a and Cumulative Energy Demand v1.09 incorporated in SimaPro 8.2.0. Details of the waste paper preprocessing, bioethanol products and distribution can be found in Leung [6]. Table 3. shows the Mill-to-Station (i.e. preprocessing, bioethanol production and distribution) and Bioethanol Production results only for the mixed paper sludge, waste cardboard and waste newspaper cases, as well as the CED results depicts the fossil energy input for bioethanol output in the three cases.

Table 3. Simulated life cycle impact analysis results (normalized by energy and mass).

| Impact Assessment | Unit | Mixed sludge | Waste cardboard | Waste newspaper |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| Global Warming Potential (Bioethanol Production) | kg $CO_{2\text{-eq}}$ / $kg_{\text{-ethanol}}$ | 1.89 | 1.98 | 2.02 |
| Global Warming Potential (Mill-to-Station) | kg $CO_{2\text{-eq}}$ /$MJ_{\text{-ethanol}}$ | 0.080 | 0.083 | 0.084 |
| | kg $CO_{2\text{-eq}}$ /$kg_{\text{-ethanol}}$ | 2.01 | 2.07 | 2.11 |
| Cumulative Energy Demand (CED, Mill-to-Station) | $MJ_{\text{-fossil fuel}}$/ $MJ_{\text{-ethanol}}$ | 1.070 | 1.064 | 1.092 |

### *3.3. Study of GHG Emission of Waste Paper-to-landfill in Hong Kong*

Paper waste shares ~20% by weight of total municipal solid waste in Hong Kong. GHGs, mainly methane ($CH_4$) are generated from decomposition of the organic content of waste paper at landfills. GHG emissions can be calculated by E = P x Emission Factor, where P is the mass of paper waste disposed at landfills in kg, and the Emission Factor is estimated to be 4.8kg $CO_{2\text{-eq}}$/kg (without considering landfill gas reuse). In considering the growing landfill gas (LFG) utilization rate, a Modified Emission Factor is presented to estimate the landfill gas (LFG) reuse impacts in Hong Kong [6]. The Modified Emission Factor can be calculated as follows:

$$\text{Modified Emission Factor} = EF_{-LFG\ combusted} + EF_{-LFG\ emitted} = 3.92\ kg\ CO_{2-eq}/kg_{-waste\ paper}$$

where $Emission\ Factor_{-LFG\ combusted}$ and $Emission\ Factor_{-LFG\ emitted}$ are determined to be 0.23 and 3.69 $kg\ CO_{2-eq}/kg_{-waste\ paper}$ respectively.The comparative results of $CO_2$ emission in "Waste paper-to-bioethanol" and "Waste paper-to-landfill" scenarios based on waste paper production of 1922 ton/day in Hong Kong are summarized in Table 4.

Table 4. Comparative GHG emission results of waste paper-to-landfill and waste paper-to-ethanol scenarios.

| Pathways | Daily $CO_{2\text{-eq}}$ emission (ton) | Daily Bioethanol Product (ton) |
|---|---|---|
| Waste paper to landfill | 7531.5 | NA |
| Waste paper to ethanol | 805.1 | 426.0 |

As can be seen, the $CO_2$ emission can be greatly reduced in the waste paper-to-ethanol pathway when compared with the waste paper-to-landfill pathway. Based on the simulated GWP value of 1.89 kg $CO_{2\text{-eq}}$ /$kg_{\text{-ethanol}}$, more than 80% $CO_2$ emission reduction can be predicted in the waste paper-to-ethanol scenario. The reuse of waste paper sources cannot only provide alternative feedstock to produce bioethanol but also relieve the heavily burdened landfills in Hong Kong. The ideal scenario for the future waste paper-to-bioethanol plant would include a combination of optimized bioethanol conversion process, abundant feedstock supply as well as favourable environmental performance.

## **4. Economic Analysis**

### *4.1. Bioethanol Production Cost*

Due to the relatively short history of the commercial bioethanol production, actual operation data for bioethanol production are not available. Luo et al [7] carried out a life cycle analysis including life cycle costing for a possible sugarcane based ethanol plant co-producing sugar and electricity. The ethanol production cost at year 2005 was estimated to be US$0.26 – 0.30/kg with no discounting and depreciation taken into account. Wang et al. [8] conducted an economic analysis for bioethanol from various waste papers using two different enzymes to determine the ethanol production cost and minimum ethanol selling price (MESP) that makes the net present value of such waste paper based plant zero with a 10% discounted cash flow rate of return over a 20 year plant life.

Based on 2015 value, the local waste paper cost was found to be within the ranged between £20/ton and £60/ton. Thus, in the absence of a dedicated techno-economic evaluation involving technology options and site selection for Hong Kong, the results presented in Wang's study [8] are assumed to hold for the local situation except those on electricity credits by selling excess electricity generation at an agreed price from bioethanol production plant back to power grid. The bioethanol production costs for Hong Kong are thus obtained, after removing the electricity credits, to be 5.07-5.86, 3.85-4.38, 5.91-6.71 and 8.97-9.86 HK$/L respectively for cardboard, office paper, newspaper and magazine. Taking an average of the above, a production cost of bioethanol from paper waste can be taken as HK$6.00/L in Hong Kong. However, there will be considerable incentive for government to subsidize on the biomass feed cost as the consumption of biomass for bioethanol production will lead to reduced landfill cost in additional to pressure on landfill space. There will thus be considerable advantage for government to grant subsidy for intake of biomass feed to ethanol production hence reducing the cost for bioethanol production from waste.

### *4.2. Cost Implications to Motorists in the Use of Bioethanol*

Observations on the trends of fuel pump price against import fuel cost for the period May 2015 – May 2016 available from Consumer Council [9] suggest that the former is usually about twice that of the latter. Hence with the conservative deduction of bioethanol production cost of HK$ 6.00/L in the above sub-section, we may take a pump selling price for bioethanol from waste cellulosic matters to be HK$ 12.00/L.

With a Hong Kong petrol pump selling price of say HK$14.50/L at present, motorists will find an E5 and E10 costing of HK$14.38/L and HK$14.25/L respectively. On the other hand, the US Department of Energy [10] states that, since ethanol contains about one-third less energy than gasoline, vehicle mileage per liter fuel will typically be 3% to 4% less on E10 and 4% to 5% on E15 than on 100% gasoline. The actual cost benefit or penalties to motorists on the same mileage basis are HK$14.66 or 101% of original petrol price for E5 and HK$14.75 or 102% of original petrol price for E10. Hence an insignificant cost penalty of 1% to 2% to motorists when using E5 and E10 respectively. Should certain electricity credits for selling excess electricity from the bioethanol production process or government subsidy on waste paper collection be granted in future, motorists would likely enjoy a cost benefit rather than cost penalty.

## 5. Difficulty in Introducing Bioethanol Fuel to Hong Kong and Implementation Plan

### *5.1. Difficulty and Constraints*

Firstly, not all the materials are compatible with bioethanol and various studies have been conducted about the material compatibility under the usage of bioethanol. These materials mainly come from components that are susceptible to be in contact with the fuel such as fuel dispenser, fuel hose, storage tank, injection pump, and combustion cylinder. Secondly, the cost of the fuel is another consideration that will affect the popularity and acceptability of the fuel. If there is no mandatory requirement for the usage of bioethanol, then the main factors that will affect the drivers' selection are the cost and environmental consideration. Thirdly, Hong Kong is a highly-congested city and it will be difficult to introduce pure ethanol (E100) as an individual fuel in Hong Kong as it would need to install new storage tanks for the fuel in gas stations. The compatibility of materials and car engines may also cause concern. Furthermore, there is no renewable energy policy that can support the use of biofuels in Hong Kong that further increase the difficulty. It will therefore be unrealistic to expect the government would change its policy and strongly support the introduction of bioethanol in a few years' time.

### *5.2. Implementation plan*

As mentioned above, there is no technical difficulty for introducing bioethanol fuel in Hong Kong. The only thing is whether the ethanol fuel would be transported from overseas or produced locally. Besides, the waste paper-to-bioethanol can reduce the carbon emission as compared with waste paper-to-landfill case. Therefore, from both the environmental and economic point of view, it is good if the local control authority can provide some incentive measures to attract investor to build waste to ethanol production plant in the city, such as to reduce land rental price for the industrial estates for such purpose. Reducing the tax for bioethanol blended fuel would also encourage the use of the low carbon fuel which would also encourage more investors for setting up relevant production facilities with the city.

Legislation is important for implementation of a certain policy. In the past, the HKSAR government has legislations regarding the tightening fuel sulphur content in the diesel fuel, such as the introduction of ultra-low sulphur diesel and Euro 5 diesel. Therefore, if the introduction of bioethanol blended gasoline is to be implemented, proper legislation is necessary. As a start, it is recommended to mandate the use of 5 to 10% bioethanol, which is in line with most of the countries currently adopted. The amount of bioethanol required for E5 and E10 will be about 27 kT and 54 kT, respectively while the estimated local production of bioethanol from wastepaper can reach 155 kT which therefore can satisfy the bioethanol demand of both scenarios.

## 6. Conclusion

The feasibility and prospects of introducing bioethanol as automotive fuel in a metropolitan city such as Hong Kong was studied. It was found that technically there is no difficulty if bioethanol is blended with gasoline at low percentage of E5 or E10. No additional infrastructure need to be constructed in existing gas refilling stations. The cost of the blended fuel will be marginally higher than existing gasoline but would be lower if tax incentive is provided to the driver. In terms of emissions, bioethanol can reduce conventional air pollutants but may increase VOC emissions, though the absolute amount may be quite low. However, if small percentage of bioethanol is introduced, no significant impact would be envisaged. It is also found that the best strategy for Hong Kong is to produce bioethanol locally, using waste feedstock such as waste paper. The LCA showed that significant amount of $CO_2$ emission can be reduced in this way. In order to introduce bioethanol successfully into Hong Kong market, the government needs to introduce new legislation for mandatory use of the fuel. Still, trial program also needs to be run to get more experience in using this clean biofuel before the full implementation.

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