Cleaner Vehicles & Fuels Workshop on 
18 May 2001

Workshop Information Booklet

Organised by The Asia Foundation and Civic Exchange
Sponsored by Lee Hysan Foundation
Dear Participant,

Depending upon the time of year, roughly fifty percent of Hong Kong’s poor air stems directly from air pollutants generated in Hong Kong—primarily from vehicles. In October 1999, Chief Executive Tung Chee Hwa announced several measures to reduce vehicular pollution, including changing taxis from diesel to LPG. But additional measures will be required if Hong Kong is to achieve acceptable air quality in future.

Civic Exchange is a non-profit public policy research organisation recently established in Hong Kong. It is currently undertaking a 7 month research project on cleaner vehicles and fuels, supported by The Asia Foundation and sponsored by Lee Hysan Foundation. In response to public concern to Hong Kong’s air pollution problems, Civic Exchange is studying alternatives to conventional diesel and petrol fuelled vehicles, and is in contact with companies and entrepreneurs who are introducing or testing these technologies in Hong Kong. The technologies under review include cleaner diesel and petrol, LPG, biofuels, natural gas, electric, hybrid and fuel cell vehicles. Civic Exchange is reviewing the different technologies in terms of effectiveness in reducing polluting and greenhouse gas (GHG) emissions, costs, safety aspects, vehicle performance, infrastructure requirements, feasibility and availability.

As part of the study, Civic Exchange and The Asia Foundation are holding this focused bilingual workshop with different stakeholders in the road transport industry. The objective of the workshop will be to gather ideas on improving vehicle emissions. The workshop will be managed using the techniques of value management to determine the concerns and keys issues regarding vehicle emissions and to listen to how technologies can be implemented in Hong Kong. Following the information phase, participants will work in smaller groups, and using creative brainstorming, discover opportunities for taking vehicle emission strategies forward. Participants can use either Cantonese or English which will be translated for the benefit of other participants.

This Information Booklet provides information on the background of the workshop and sets the scope of the problem. A summary of the results of the research Civic Exchange has carried out into alternative technologies, and how they could be applied in Hong Kong are incorporated into a briefing document which forms part of this Information Pack. Please review all the information contained in this workbook carefully.

It is important for you to become familiar with the material, to ensure that the workshop receives the benefit of your full and enthusiastic participation. Enter into discussion sincerely and enthusiastically, give freely of your experience but don’t digress or waffle. Actively listen to other participants, one person talking at a time and be patient and appreciate other people’s view points

Please leave all your work issues at the door and switch off your mobile phone and pager. We believe that you will find this workshop most constructive and beneficial and look forward to meeting you all.

Civic Exchange
April 2001
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1. THE CLEANER VEHICLES & FUELS WORKSHOP

1.1 Venue: Hong Kong Academy of Medicine
99 Wong Chuk Hang Road, Aberdeen

1.2 Date: Friday 18th May 2001.

1.3 Programme:

8.30am Registration
9.00am Introduction by Christine Loh, Civic Exchange & Allen Choate, The Asia Foundation.
9.10am Introduction to Cleaner Vehicles & Fuels Strategy
9.30am Introductions (Grp)

Identification of Key Issues & Concerns

10.15am Coffee / Tea Break
10.45am Sharing Issues, Concerns & Key Areas of Importance (Wkshp)
11.15am Presentations – Implementing Technologies: (Wkshp)
   Cleaner Diesel & Retrofit Technologies
   Electric and Hybrid Vehicles
   Bio Fuels
   LPG & Natural Gas
   Fuel Cells

11.40am Questions & Discussion
12.00pm Creative Thinking & Idea Generation (Grp)

12.30pm Lunch Break
1.30pm Continue Creative Thinking
2.30pm Presentation of Group Ideas (Wkshp)

3.15pm Coffee / Tea Break
3.30pm Summary & Discussion (Wkshp)
4.00pm Action Plans (Grp)
5.00pm Presentation & Discussion of Action Plans
5.30pm Close

2. PARTICIPANTS

One of the success factors of group problem solving is the selection of a group of people who collectively have the best possible knowledge and understanding to resolve issues and evaluate solutions relating to the problem. Not everyone who is involved in the issue can be present at the workshop. It is, however, essential to have all the stakeholders - who will be affected by decisions made during the study - represented. Representatives of transport operators, vehicle suppliers, government regulators, oil companies, utilities and political and environmental organisations have been invited together with proponents of alternative technologies. The participants have been invited to contribute their knowledge of the Industry, their technical, intellectual and creative resources and their experience to contribute effectively to the problem solving.
Representatives from the following organisations have been invited to join the workshop.

<table>
<thead>
<tr>
<th>Transport operators/associations</th>
<th>Exxon-Mobil</th>
<th>Environmental Protection Department</th>
</tr>
</thead>
<tbody>
<tr>
<td>KMB</td>
<td>Caltex</td>
<td>Electrical &amp; Mechanical Services Dept</td>
</tr>
<tr>
<td>Citybus</td>
<td>BP</td>
<td>Transport Bureau</td>
</tr>
<tr>
<td>New World First Bus</td>
<td>CRC</td>
<td>Transport Dept</td>
</tr>
<tr>
<td>HK Kowloon Taxi &amp; Lorry Owners Assoc</td>
<td>Vehicle/parts suppliers/manufacturers</td>
<td>Planning &amp; Lands Bureau</td>
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<tr>
<td>Kowloon Taxi Owners Assoc</td>
<td>Motor Traders Assoc</td>
<td>Fire Services Dept</td>
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<tr>
<td>United Friendship Taxi Owners &amp; Drivers Assoc</td>
<td>Dah Chong Hong</td>
<td>Police</td>
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<tr>
<td>HK Container Tractor Owner Assoc</td>
<td>Daimler Chrysler</td>
<td>Finance Bureau</td>
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<tr>
<td>Rights of Taxi Owners and Drivers Assoc</td>
<td>Dennis</td>
<td>Economic Services Bureau</td>
</tr>
<tr>
<td>GMB Maxicab Operators GenAssoc</td>
<td>Scania</td>
<td>Land Transport Agency</td>
</tr>
<tr>
<td>Goods Vehicle Fleet Owners Assoc</td>
<td>Yardway</td>
<td>Guangzhou EPB</td>
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<td>The HK Taxi &amp; PLB Association</td>
<td>Bosch</td>
<td>Educational/Professional</td>
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<td>PLB Association</td>
<td>GM Asia Pacific</td>
<td>University of Hong Kong,</td>
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<tr>
<td>HK Vehicle Repair Merchants Assoc</td>
<td>Technology providers</td>
<td>HK Polytechnic University</td>
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<tr>
<td>HK, KLn &amp; NT Public and Maxicab Light Bus Merchants United Association</td>
<td>Cheung Kong Infrastructure</td>
<td>HKUST</td>
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<td>Taxi Associations Federation</td>
<td>Goldpeak Industries Ltd</td>
<td>HK Institute of Vocational Education</td>
</tr>
<tr>
<td>HK Union of Light Van Employees</td>
<td>Enviropower Ltd/AEL</td>
<td>HK Institute of Engineers</td>
</tr>
<tr>
<td>HK Dumper Truck Drivers Assoc</td>
<td>Vicmax</td>
<td><strong>Political parties</strong></td>
</tr>
<tr>
<td>MTRC</td>
<td>Ecogas Pacific Rim Ltd</td>
<td>Democratic Party</td>
</tr>
<tr>
<td>KCRC</td>
<td>Dunwell Eng Co</td>
<td>DAB</td>
</tr>
<tr>
<td><strong>Utilities</strong></td>
<td>Hednesford</td>
<td>Liberal Party</td>
</tr>
<tr>
<td>CLP Power</td>
<td>Sunland</td>
<td>Frontier</td>
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<td>Hongkong Electric Co Ltd</td>
<td>Bioclear</td>
<td><strong>Environmental Organisations</strong></td>
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<tr>
<td>Towngas</td>
<td>Gaia</td>
<td>The Conservancy Association</td>
</tr>
<tr>
<td>Swire Sita</td>
<td>Bioenergy (HK) Ltd</td>
<td>Friends of the Earth</td>
</tr>
</tbody>
</table>

April 2001
3. **PURPOSE OF THE WORKSHOP**

The purpose of the workshop is to consider how to reduce vehicle emissions in Hong Kong. The study is limited to Hong Kong, ie it is not looking at possible pollution from Guangdong. Also, it is not considering other forms of transport, nor switching from one form to another (ie road to rail).

4. **OBJECTIVES OF THE WORKSHOP**

1. To gather ideas on how to pursue ways to improve the vehicle emissions.
2. To develop action plans to take vehicle emissions strategies forward.
3. To provide a network for ongoing development of strategies.

5. **INFORMATION STAGE - PROVISIONAL TOPICS & SPEAKERS**

To enable the group to create and evaluate solutions and arrive at the best possible outcome of the study, each participant needs to be able to appreciate the values, perspectives and differing points of view of the other participants.

This will initially be carried out by each participants sharing with each other and the whole workshop their concerns and defining and discussing what is of key importance to them in this area. In addition, some academics working in the alternative technologies will be invited to share with the workshop their views on how these technologies could be implemented in Hong Kong.

A briefing paper, which looks at the alternatives cleaner vehicle technologies, is appended. However, the aim of the workshop is not to replicate any views stated in the briefing paper or by the presenters but to obtain consensus amongst all participants on ways of implementing new, cleaner technologies.

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Speaker</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cleaner Diesel &amp; Retrofit Technologies</td>
<td>Kong Ha - EPD</td>
</tr>
<tr>
<td>Electric &amp; Hybrid Vehicles</td>
<td>Danny Sutanto – Dept Electrical Eng., HK Poly U</td>
</tr>
<tr>
<td>Bio Fuels</td>
<td>Dennis Leung – Dept Mechanical Eng., HKU</td>
</tr>
<tr>
<td>LPG &amp; Natural Gas</td>
<td>Martin Wong – Independent Consultant</td>
</tr>
<tr>
<td>Fuel Cells</td>
<td>James Cannon – Energy Futures Inc</td>
</tr>
</tbody>
</table>

6. **VALUE MANAGEMENT**

The Value Management methodology is a structured systematic approach to addressing and solving a problem. It harnesses the creative powers of a group of people in harmony to achieve more than the sum total. The structure of the workshop involves a series of very specific steps as follows:

1. Information Stage – where the views of all participants are shared allowing a common understanding of the problem and possible solutions.
2. Analysis stage – where the true nature of the problem is analysed and participants’ key areas of importance are shared.
3. Idea generation – a divergent phase where all ideas are welcomed and solutions are brainstormed.
4. Evaluation of Ideas – where the many ideas generated in the creative stage are culled so that those worth developing can be identified.
5. Development of Ideas – where the most worthwhile ideas are taken forward for further consideration.

7. **SCOPE OF THE PROBLEM**

7.1 **Current Air Pollution**
- Air quality in Hong Kong consistently fails to meet Air Quality Objectives\(^1\) (AQOs). Roadside concentrations of Respirable Suspended Particulates (RSP)\(^2\) and oxides of nitrogen (NOx)\(^3\) regularly exceed health standards
- The 24-hour AQOs were exceeded 93 times in 1999 alone.
- Regional ozone\(^4\) problem with 50% increase in levels since 1990.

7.2 **Sources of Air Pollution**
- Road based vehicles account for 47% of RSP, 87% of Volatile Organic Compounds (VOCs)\(^5\) and 32% of NOx emitted in Hong Kong by all sources.
- Diesel and petrol vehicles are the primary cause of street level pollution in the SAR. Diesel vehicles account for nearly 98% of RSP and 80% of nitrogen dioxide (NO2) from all vehicles.

7.3 **Hong Kong’s Road Vehicle Fleet**
- In 1999, over 570,000 vehicles registered in Hong Kong.
- Diesel vehicles comprise about 31% of SAR’s vehicle fleet and 61% of total vehicle mileage (1997). Most are commercial vehicles including: 18,000 taxis, over 12,000 buses, 6,500 light buses, 87,000 light goods vehicles (LGV) and 43,000 medium goods vehicles (MGV) and heavy goods vehicles (HGV) (1999).
- 71% of all vehicles run on petrol, 90% of which are private vehicles.
- As of March 2001, 7000 LPG taxis registered
- 56 electric vehicles registered as electric vehicles

7.4 **Contribution to pollution**
- Main vehicular sources of RSP are MGV (29%), diesel LGV (25%), diesel taxis (26%) and franchised buses (11%).

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\(^1\) Health based standards for different air pollutants. The Air Pollution Index (API) is based on a composite of different AQOs.

\(^2\) Fine particulates with a diameter of less than 10 micrometres (a millionth of a metre). RSP causes respiratory illness; reduced lung function and increased cancer risk.

\(^3\) “NOx” collectively refers to nitrogen dioxide (NO\(_2\)), nitric oxide (NO), nitrous oxide (N\(_2\)O). NO\(_2\) a brown gas, contributes to urban photochemical smog and acid rain. NO\(_2\) causes respiratory irritation, increases susceptibility to respiratory infection and impairs lung development.

\(^4\) Ozone is not a directly emitted pollutant but is formed from a photochemical reaction between Volatile Organic Compounds (VOCs) and NOx. It is toxic to humans at levels above 0.1ppm.

\(^5\) VOCs contribute to ozone. They cause eye, respiratory and skin irritations, and can be carcinogenic.
• Main vehicular sources of NOx are MGV (29%), petrol private cars (22%), franchised buses (16%), diesel LGV (13%) and diesel taxis (12%).
• Main vehicular sources of VOCs are motorcycles and petrol LGV (29%), petrol private cars (28%) and MGV (18.5%)

7.5 Current control programme
• Hong Kong Air Quality Objectives are not legal requirements. When they are exceeded there is no legal consequence. This differs from other countries where similar objectives are mandatory which provides more impetus for the Government, oil companies and vehicle manufacturers to act to reduce emissions and improve air quality.
• Government’s current control programme for vehicle emissions comprises:
  • tighter fuel and emission standards. Newly registered vehicles in Hong Kong must meet Euro 3 (or 2 in some cases) standards.
  • introduction of cleaner fuels such as liquidified petroleum gas (LPG) for taxis and Ultra Low Sulphur Diesel (ULSD).
  • Provision of subsidies for in-use light duty diesel vehicles (less than 4 tonnes) retrofit devices to reduce particulate emissions and for purchase of new LPG taxis.
  • Annual emission tests for in-use vehicles. Transport Department (TD) tests the smoke density of 10% of in-use vehicles on a random basis as part of its annual licensing, using a free acceleration test. TD has one chassis dynometer for light and heavy goods vehicles. TD also tests LPG taxis for CO and hydrocarbons and commercial petrol vehicles for CO and smoke as part of their annual license renewal. Private cars over 6 years old must be inspected annually including an emission check.
  • Random emission tests. Vehicles emitting excessive (over 60 HSU) black smoke, if caught by the Police, are subject to a $1000 fine. If spotted by an EPD spotter the vehicle is summoned for testing (but no fine). Chassis dynamometers have been used to test vehicles below 5.5 tonnes, and were extended to heavy duty vehicles in December 2000.

7.6 Future projections for air quality
• Government estimates that Hong Kong should be able to meet its current AQOs by 2005, assuming no increase in ambient, regional air pollution levels and no increase in vehicles.
• No accurate quantitative data on the contribution of cross-border pollution available but could be up to 30% in winter-time. Trends suggest that cross-border pollution is increasing.
• Under Transport Department’s high growth scenario, by 2016, private cars could increase by 300% goods vehicles by 100% and cross-boundary traffic by 400%. Under this scenario, all monitoring stations would report much worse air quality simply due to increase in vehicle numbers.

7.7 Greenhouse Gas Emissions
• Transport consumes more energy than any other single sector, and over twice that of industry in Hong Kong. In 1998, the latest figures available, transport accounted for 36% of primary energy consumed in Hong Kong.

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6 EPD and its Guangdong counterpart have just completed a joint 18-month study to identify the nature and extent of air pollution in the entire Pearl River Delta. Results should be available mid 2001.
• Hong Kong’s per capita emissions are low compared to many developed countries, probably due
to short commuting distances, low percentage of car ownership and well developed mass transport
system.
• Diesel oil accounts for nearly a quarter of the total annual emissions of CO₂ although this does not
include illegal or untaxed sources of diesel which could be significant.⁹
• With a doubling of the vehicle fleet predicted by 2016 in a worst case, CO₂ emissions will rise
accordingly.
• Hong Kong has no policy to reduce CO₂ emissions.

8. WHY CLEANER FUELS AND VEHICLES?

Clearly, current measures to control air pollution will not be sufficient to reverse present trends.
Reducing pollution from vehicles requires a comprehensive strategy comprising:

1. Proper maintenance of in-use vehicles
2. Clean fuels
3. Increasingly stringent emissions standards for new vehicles
4. Traffic and demand management

While (4) is undoubtedly important and worthy of serious study this workshop intends to focus on (1-3)
the introduction and maintenance of cleaner vehicle technologies.

This research paper examines the following current and developing technologies:

Cleaner diesel and retrofit technologies  Cleaner petrol
LPG  Natural gas
Ethanol  Biodiesel
Battery electric vehicles  Trolley Buses
Hybrid vehicles  Fuel cell (hydrogen) vehicles

The technologies were assessed in terms of the following: (1) effectiveness in reducing RSP, NOx and
VOCs, the vehicle pollutants of most concern to Hong Kong; (2) overall lifecycle emissions of
greenhouse gases; (3) costs; (4) infrastructure costs and requirements; (5) vehicle performance; (6)
safety; (7) availability in Hong Kong; (8) status of the technology worldwide and in Hong Kong, and (8)
applicability to Hong Kong. Details can be found in the appendix.

A comparison of the emissions performance, lifecycle greenhouse gas emissions and costs are
summarised in the following sections.

9. SUMMARY OF POLLUTION REDUCTION PERFORMANCE

There are numerous studies documenting emissions performance for different technologies. However,
these studies often record a wide variation in results even for the same technology. This variation may

4487-4498 An EPD study on greenhouse gas emissions is due to be published soon.
be due to an artefact of the testing procedure, such as the type of vehicle tested or the test cycle used.\textsuperscript{10}

To minimize such variations, studies have been chosen which have tested a range of technologies under approximately the same test conditions. While the absolute figures may be different from that likely to be experienced in Hong Kong, the relative performance of different technologies may be ascertained.

This report has focussed on 3 main pollutants: RSP, NOx and Volatile Organic Compounds (VOCs). RSP and NOx are health-threatening pollutants are regularly present at elevated levels in Hong Kong. VOCs can be toxic upon direct exposure and contribute heavily to ozone pollution, which is a growing problem in the region.

Figures 1-3 provide a comparison of lifetime emissions of RSP, NOx and total hydrocarbons (includes non volatile hydrocarbons such as methane) for some of the technologies for different vehicle types.\textsuperscript{11}

- All alternative technologies show significant improvements in RSP emissions, even compared to ULSD.
- For passenger and light goods vehicles, ULSD shows significantly higher emissions of NOx compared to other technologies.
- For single decker buses CNG and LPG show improvements in NOx emissions over ULSD.
- CNG vehicles show the largest emissions of total hydrocarbons, though much of this is likely to be methane, which does not contribute to ozone formation.
- For passenger vehicles petrol is also a large source of hydrocarbons.

10. SUMMARY OF LIFE-CYCLE GREENHOUSE GAS EMISSIONS

Several greenhouse gases (GHGs) contribute to global climate change. The transport sector principally emits CO\textsubscript{2} but also emits two other important GHGs, methane (CH\textsubscript{4}) and nitrous oxide (N\textsubscript{2}O). Both CH\textsubscript{4} and N\textsubscript{2}O are more potent GHGs than CO\textsubscript{2}. Hence, they are generally reported in terms of equivalent emissions of CO\textsubscript{2}.\textsuperscript{12}

In line with the December 1997 Kyoto Climate Change Convention, many developed countries are now considering strategies to reduce emissions of greenhouse gases. For example, the European Commission aims to reduce CO\textsubscript{2} emissions from new cars sold in the European Union to an average of 120g/km, a reduction of about a third from the current average, through voluntary commitments by European vehicle manufacturers, fiscal measures and fuel economy labelling.

Hong Kong currently has no legislation or strategies to reduce GHGs here, but this is likely to change. Any technology Hong Kong adopts to reduce tailpipe emissions must also take into account lifecycle GHG emissions (from well to wheels). This includes emissions during production, fuel processing, distribution, vehicle manufacture and operation.

\textsuperscript{10} For example, using the same vehicle and same fuel, an urban, stop-start test cycle will often produce much higher emissions than a highway, steady-driving test cycle. Similarly, testing the same fuel on vehicles of different ages (and therefore emission standards) can also yield quite different results.


\textsuperscript{12} CH\textsubscript{4} is converted to its CO\textsubscript{2} equivalent by multiplying by 21 and N\textsubscript{2}O is converted to its CO\textsubscript{2} equivalent by multiplying by 310.
This report has tried to cite studies that compare different technologies using similar assumptions. This will hopefully reduce variations attributable to local conditions rather than the technologies themselves. Obviously, local circumstances greatly impact GHG emissions, but it is beyond the scope of this study to examine life cycle emissions for Hong Kong. Nonetheless, the studies provide a rough comparison of different technologies on a relative basis. The absolute figures are subject to many assumptions.

Figures 4-6 provide comparisons of lifecycle GHG emissions associated with different technologies.\textsuperscript{13-14} Figures 4 and 5 shows lifecycle GHG emissions for passenger vehicles, the latter based on technologies believed to be in commercial use by 2020. Figure 4 shows electric, hybrid and fuel cell vehicles reduce GHG emissions significantly due to the improved fuel economy of the vehicle. Figure 5 shows hybrid vehicles to be the most efficient. Considerable uncertainty exists on the estimates for fuel cell vehicles and depends on the source of fuel energy. For heavy duty buses, diesel hybrid buses and hydrogen fuel cell buses show the lowest emissions of GHGs.

\section*{11. COSTS AND INCENTIVES FOR DIFFERENT TECHNOLOGIES}

\begin{table}
\caption{Relative costs (HK\$) for cleaner passenger vehicle technologies compared to petrol}
\centering
\begin{tabular}{|c|c|c|c|c|}
\hline
\textbf{Technology} & \textbf{Infrastructure} & \textbf{Vehicle} & \textbf{Operating}\textsuperscript{15} & \textbf{Maintenance} \\
\hline
Regular petrol & Baseline & Baseline & \$12/L @ 0.1L/km = \$1.2/km & Baseline \\
ULSD & Same & Slightly more & \$6/L @ 0.07L/km = \$0.4/km & Lower \\
Cleaner petrol & Same & Same & Additional 20-30 cents/L (50ppm S) \textsuperscript{16} & Lower \\
LPG & Significant & Slightly more & \$2.01/L @ 0.1L/km= \$0.2/km & Lower or comparable \\
Biodiesel & Slightly higher & Slightly more & \$5.4/L \textsuperscript{18} @ 0.07/km = \$0.4/km & Lower or comparable \\
Ethanol & Slightly higher & Same & \$13/L \textsuperscript{19} @ \$0.1L/km = \$1.3/km & Similar \\
Electric & Higher & +50-100\% & Less 20\%.\textsuperscript{20} & Less 60\% \\
Natural gas & Significant & +15-25\% \& +15-20\%? & Cheaper\textsuperscript{21} & Comparable \\
Hybrid & Same & +100\%.\textsuperscript{22} & \$0.56/km\textsuperscript{23} (less 30\%) & \\
\hline
\end{tabular}
\end{table}

\textsuperscript{13} Transportation Table of the National Climate Change Process (1999). Alternative and Future Fuels and Energy Sources for Road Vehicles.
\textsuperscript{15} Fuel efficiency figures taken from Transportation Table of the National Climate Change Process (1999). Alternative and Future Fuels and Energy Sources for Road Vehicles.
\textsuperscript{16} Price differential in the UK for petrol with 50ppm sulphur
\textsuperscript{17} This is at dedicated LPG filling stations. Cost per km for LPG from converted stations would be \$0.54/km
\textsuperscript{18} From virgin vegetable oil. From collected waste oil could be higher. This does not include duty.
\textsuperscript{19} Directly converted US costs. Note this includes large subsidies to ethanol producers. Canadian figures indicated HK\$2-2.5/L more than petrol.
\textsuperscript{20} Cleaner Vehicles Taskforce (2000). An Assessment of the Emissions Performance of Alternative and Conventional Fuels. DETR, UK
\textsuperscript{21} Honda Civic CX has city driving efficiency of 11 litres per km (gasoline equivalent)
Table 2: Relative costs (HK$) for cleaner bus technologies compared to diesel

<table>
<thead>
<tr>
<th>Technology</th>
<th>Infrastructure</th>
<th>Vehicle/capital</th>
<th>Operating</th>
<th>Maintenance</th>
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<tr>
<td>ULSD</td>
<td>Baseline</td>
<td>Baseline $2.3M (^{24})</td>
<td>Baseline $&lt;6/L (^{25})</td>
<td>Baseline</td>
</tr>
<tr>
<td>CRTs</td>
<td>N/A</td>
<td>$25,000-40,000</td>
<td>Same</td>
<td>Slightly higher</td>
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<tr>
<td>Euro 3</td>
<td>Same</td>
<td>Additional $10,000</td>
<td>Same</td>
<td>Same</td>
</tr>
<tr>
<td>Biodiesel</td>
<td>Slightly higher</td>
<td>Same</td>
<td>$5-6/L</td>
<td>Same or lower</td>
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<tr>
<td>Natural gas</td>
<td>Significant</td>
<td>+30-35%(^{%})</td>
<td>Not known but likely to be cheaper</td>
<td>Same or slightly higher</td>
</tr>
<tr>
<td>Trolley Bus</td>
<td>Significant</td>
<td>$3.7M</td>
<td>Slightly higher</td>
<td>Higher</td>
</tr>
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</table>

Cost is a critical factor in assessing alternative technologies and their applicability to Hong Kong. The costs of conventional and alternative fuels and vehicles in Hong Kong is significantly influenced by the amount of government taxes and duties on that technology, including high land premiums for fuel filling stations, fuel duties, first registration tax for import of new vehicles and annual license fees.

Many alternative technologies involve increased costs, either capital or operational, due to increased processing of the fuels, development costs or economies of scale. Most alternative technologies in other parts of the world have only been possible through the introduction of government incentives or mandates. For example, California statutes require that a set proportion of all vehicles in the state achieve low emissions. The Hong Kong government has encouraged the uptake of cleaner technologies through the following:

- Reduction in duty for Unleaded Petrol (prior to the banning of high lead petrol)
- Waiver of First Registration Tax for electric vehicles
- Reduction in duty for Ultra Low Sulphur diesel
- Waiver of land premium for dedicated LPG filling stations to reduce the price of LPG

But Hong Kong also has disincentives to cleaner technologies, including the following:

- Franchised bus operators and government vehicles pay no duty on fuel
- Many off-road vehicles use industrial diesel which has no duty
- Many cross-border vehicles use much cheaper mainland sulphur diesel

11.1 Costs of Technologies
Tables 1 and 2 summarise the relative costs of some of the technologies for passenger vehicles and large buses. For the technologies presently in use in Hong Kong the data is quantitative and more reliable. For technologies not yet introduced into Hong Kong, such as natural gas or hybrids, many of the costs are approximate or qualitative only (indicated by shading). The data for fuel cells is even more speculative since the technology is still under development and therefore has not been included.

\(^{22}\) Difficult to estimate. For Prius, Toyota is reportedly subsidising the costs heavily.

\(^{23}\) Based on Toyota Prius with efficiency of 18L per km fuel efficiency

\(^{24}\) Cost for new double decker Euro II bus

\(^{25}\) Franchised bus companies do not pay diesel duty and get bulk discounts from oil companies.
The tables show that the high capital costs of some of the cleaner vehicle technologies may be offset to a certain extent by the lower operating costs (fuel efficiency and maintenance). Infrastructure costs may still be an issue that requires government assistance. The costs of alternative fuels is greatly influenced by government duties.

11.2 Possible incentives
If the Government decided that it would be in the interests of Hong Kong to promote a particular technology the following measures could be considered as fiscal incentives:

*Capital*
- Waive or reduce land premium for filling stations or distribution points
- Waive First Registration Tax (e.g. EVs)
- Provide direct grants towards costs of new vehicles (e.g. new LPG taxis)
- Tax credits for trade in of older vehicles (e.g. for passenger cars over 10 years old)
- Provide direct grants for retrofit technologies (e.g. grant for particulate traps)

*Operation*
- Waive or reduce duty on fuel (e.g. reduction in duty on ULP and ULSD)
- Base duty on energy content rather than volume for all fuels
- Waive duty for fuel for certain vehicles (e.g. franchised buses)
- Waive or reduce Annual Licence Fees for vehicles
- Provide preferential parking fees or spaces for cleaner vehicles
- Base road pricing on vehicle performance – lower charge for cleaner vehicles

12. SUMMARY OF CONSTRAINTS

The following is a summary of some of the main constraints identified by the researchers or the people interviewed as part of this study. This does not imply that the constraints are insurmountable but rather the issues that would need to be dealt with if such technologies were to be introduced. It should be noted that many of the people interviewed for this report also noted a general constraint being the lack of education of the Hong Kong public on environmental issues.

12.1 Cleaner Diesel
- Higher particulate emissions than most alternative technologies.
- Diesel vehicles need regular maintenance to ensure good emissions performance.
- Costs of fitting retrofit devices.

12.2 Cleaner Petrol
- Increased cost.
- Relatively high greenhouse gas emissions compared to alternative technologies.
- Low availability of fuels in Asia.

12.3 LPG
- Lack of suitable sites for more filling stations
- Limit on existing bulk storage capacity. Planning for new site could take up to 5-10 years.
- Safety issues associated with larger numbers of LPG vehicles on the roads and the supply of LPG to filling stations in bulk road tankers
- Low propane content of LPG used in Hong Kong limits application beyond light goods vehicles.
12.4 **Biodiesel**
- Cost (HK$5.4/L) relative to ULSD (HK$2.27/L) even without fuel duty
- Lack of distribution system although existing petrol/diesel system could be adapted.
- Use can increase NOx emissions slightly

12.5 **Ethanol**
- Cost relative to diesel and petrol.
- One fifth less energy content than petrol. More frequent refuelling required.
- Separates if contaminated by water. Can add to distribution costs—requires truck or rail shipment.
- More than 85% ethanol fuel requires special engines, tanks and components.

12.6 **Battery Electric Vehicles**
- Range for certain vehicles.
- High capital costs of vehicles.
- Need for installation of charging stations.
- Additional weight of batteries would require government relaxation of vehicle weight (for PLBs)
- Charging time required.
- Battery disposal.

12.7 **Trolley buses**
- Funding for infrastructure – could be done by consortium of companies or government owned corporation. However no policy to provide for this.
- Elaborate wiring required in major corridors due to large flows of vehicles and need for overtaking.
- Finding land for substations in busy urban area.
- Possible visual impact.
- Legislation needed to make it possible to introduce such a system in Hong Kong although this could be relatively straightforward.

12.8 **Hybrid Vehicles**
- More expensive.
- Low availability in Hong Kong.
- Specialized mechanics and garages required for electric battery.

12.9 **Natural Gas**
- Lack of NG transportation infrastructure until (and if) Towngas is replaced by natural gas. NG would have to be transported in cylinders or tankers in the meantime.
- If LNG were transported by tanker in large quantities, risk assessment would need to be carried out. Risk expected to be similar to LPG tankers.
- Double-decker bus length would need to be increased from 12m to 13.5m to accommodate CNG tank.
- Franchised bus operators need fast refuelling to refuel 400 buses in 3-4 hours.
- For utilisation of landfill gas, need to make contractual arrangements with EPD.

12.10 **Fuel Cell Vehicles**
- Technology not fully mature. No vehicles commercially available. First models not likely to be available in Hong Kong for several years at the earliest.
• Prohibitively expensive at present. Conventional petroleum engine now costs US$2000-3000, a comparable fuel cell stack costs about US$35,000.\(^{26}\) Estimated cost of vehicle even higher.
• No distribution system for either of most promising fuels: methanol or hydrogen. Current production of both fuels also insufficient for estimated demand.

GLOSSARY

**ac:** alternating current  
**BEV:** Battery Electric Vehicle  
**CLP:** China Light &Power  
**CNG:** Compressed Natural Gas  
**CO:** Carbon monoxide  
**CO\(_2\):** Carbon dioxide  
**CRT:** Continuous Regenerating Trap  
**dc:** Direct current  
**DOC:** Diesel Oxidation Catalyst  
**EMSD:** Electrical & Mechanical Services Dept  
**EPD:** Environmental Protection Dept  
**FCV:** Fuel Cell Vehicle  
**GHG:** Greenhouse Gas  
**GM:** General Motors  
**HEV:** Hybrid Electric Vehicle  
**ICE:** Internal Combustion Engine  
**Km:** Kilometre  
**KV:** Kilo-volt  
**L:** Litre  
**LNG:** Liquified natural gas  
**LPG:** Liquified petroleum gas  
**NENT:** North east new territories (landfill)  
**NG:** Natural gas  
**NGV:** Natural gas vehicle  
**NO\(_x\):** Oxides of nitrogen  
**PLB:** Public light bus  
**SENT:** South East New Territories (landfill)  
**SO\(_x\):** Oxides of sulphur  
**TD:** Transport Dept  
**THC:** Total hydrocarbons  
**ULSD:** Ultra low sulphur diesel  
**V:** Volts  
**VOC:** Volatile organic compounds  
**WENT:** West New Territories (landfill)

ACKNOWLEDGEMENTS

Civic Exchange and the Asia Foundation gratefully acknowledges the help of the following in research and translation for this report: Vivian Kwok Man-chu, Edward Lo (Worcester Polytechnic Institute, MA), Karen Zhu (Worcester Polytechnic Institute, MA), Professor John Zeugner (Worcester Environmental and Energy Study Institute (EESI), “Fuel Cell Fact Sheet”. February 2000.

Polytechnic Institute, MA) Peggy Yung. We would like to give special thanks to Vincent Wong for translating this report.

We would also like to particularly thank the following organisations and individuals who kindly provided information and assistance:

Better Environment Hong Kong: Steve Choi; Bioclear: Martin Gould, Grand C Ng; Bioenergy Technologies (HK): Richard W Lee; Bosch: Rainer Volk, Calvin Yip; BP: Ted Harvey; Business Environment Council: Andrew Thomson; Cheung Kong Infrastructure: Barrie Cook; Citybus: John Blay; CLP Power: Charles Wong; CLP Research Institute: Richard Entwistle; Conservancy Association: C N Ng, Lister Cheung, Kate Choy; Dah Chong Hong: Carman Ho Ka Man, Tong Kwok Kei; Daimler Chrysler: Karin Malstrom; Democratic Alliance for the Betterment of Hong Kong: Roger Cheung; Dennis/TransBus International: Richard Winkworth, Roger Heard, Alan McClafferty; Dunwell: Daniel Cheng, Victor Li, Michael Mohtadi; Ecogas Pacific Rim Ltd: Brenda Smith; Electrical & Mechanical Services Dept: K K Lam, Vincent Chow Hau-keung, Tseng Hing-wah; Environment & Food Bureau: Thomas Chow; Environmental Protection Department: C W Tse, Kong Ha, Carol Wong, W C Mok, H N Lau, W M Pun, Matthew Tsang; Enviropower Ltd: Lilian Chan; European Union: Paul Greening; ExxonMobil: Jane Tang, Yvonne Chan; Gammon Construction: James Graham; Fire Services Dept: C F Liu; First Bus: John Whitworth; Friends of the Earth: Eric Walker; Gaia Energy: Simon Chiu, Akihito Azuma; Gammon Construction: James Graham; GM Asia Pacific: David Tulauskas, Steven Bridson; GM Maxicab Operators General Association: Hiew Moo Siew; Goldpeak: Andrew Ng, Kevin Yiu Kai Man; Government Land Transport Agency: Sam Hui Wai-kwong; Green Power: Dr L K Cheng; Guangzhou Environmental Protection Bureau: He RongYou, Zhang Sheng Jian; Hednesford: Sjouke Postma; HK Container Tractor Owner Association: Ricky Wong; HK Dumper Truck Drivers Association: Ho Hung Fai; HK Institute of Vocational Education: Iain Seymour-Hart; HK Kowloon and New Territories Public & Maxicab Light Bus Merchants United Association: Leung Hung, Tam Chun Tat, Paulus Hui; HK Union of Light Van Employees: Y M Lam; HK Vehicle Repair Merchants Association: Ringo Y P Lee; Hong Kong Electric Co: Gary Chang; Hong Kong Kowloon Taxi & Lorry Owners Association: Man Hon Ming, Wong Po Keung, Cheng Hon Kwai; Hong Kong Polytechnic University, Dept Civic Engineering: Hung Wing Tat; Hong Kong Polytechnic University, Dept Electrical Engineering: Dr Danny Sutanto, Dr Edward W C Lo, Dr Eric Cheng; Hong Kong University of Science & Technology: Dept Chemical Engineering: David Hui Chi-wai; James Cannon; KCRC: Chris Lam Fung Yip; KMB: Kane Y H Shum; Kowloon Taxi Owners Assoc Ltd: Yum Tai Ping; Liberal Party: Linda Chung, Luk Hon Tak, Y M Choi, Cherry Cheung; Martin Wong consultants: Martin Wong; Mercedes-Benz: Edward Chalk; MTRC: Dr Glenn Frommer; PCCW: Yeow Yu-pang; Planning & Lands Bureau: Daniel Cheng; Public Light Bus Association: Fung Chuen; Quantum Technologies: Skip Miller, Roger Toale; Rights of Taxi Owners and Drivers Assoc Ltd: Lau Kin-won, Chan Kim Fung, Yu Chui Kan; Scania: Torsten Linder, Povarsson; Shell: Peter Robinson, Irene Chan; Sun Bus Ltd: Simon Tu; Sunland: Carmen Wong, LT Sung; Swire Sita: Caroline Rousseau; Taxi Associations’ Federation: Ng Kwok Hung; The Frontier: Emily Lau; Towngas: Sam Shum; Transport Bureau: Benjamin Mok; Transport Dept: Alan Lui, Y W Chiu, Larry Y M Li; UEE Ltd: Casey K C Man; United Friendship Taxi Owners & Drivers Association: Wong To; University of Hong Kong Dept of Mechanical Engineering: Dr Dennis Leung; University of Hong Kong, Dept Electrical Engineering: Prof C C Chan; University of Hong Kong, Dept of Mechanical Engineering: Dr Cheung Kie Chung; Viasia Ltd: Chan Yiu; Vicmax: Rayne Chow, C P Lo; Yardway: Mike Hudson, James Rourke, Yim Wing Han; Young Children School Minibus Operators Assoc Ltd: Ms Ng Wong Ka-wing.
APPENDIX: SUMMARY OF TECHNOLOGIES

A. CLEANER DIESEL AND RETROFIT TECHNOLOGIES

What is cleaner diesel?

Diesel engines

- Improvements in diesel engine standards have reduced emissions significantly over last 30 years.
- More recent engine improvement technologies include the Direct Injection (DI) diesel engine which increases fuel efficiency by 15%, exhaust gas recirculation (EGR) to reduce NOx on both heavy- and light-duty diesel engines and the common rail injection system. However the use of EGR aggravates particulates, making after-treatment necessary.
- Hong Kong adopts European (Euro) engine standards, with Euro 3 the current standard for light duty vehicles since January 2001. Euro 3 will be adopted for heavier vehicles in October 2001. Euro 4 standards will likely require after-treatment devices, such as particulate traps and NOx after-treatment devices.

Diesel fuel

- Improvements in diesel fuel have reduced emissions significantly over the last 10 years.
- Lower sulphur content reduces particulate emissions, although diminishing returns at lower levels of sulphur. Main advantage of lower sulphur diesel is to allow use of catalytic convertors, that can be disabled by high sulphur diesel, which reduce emissions further.
- Hong Kong introduced Ultra Low Sulphur Diesel (ULSD) with sulphur content less than 50ppm (0.005%) in July 2000, essential for engines to comply with Euro 4 standards.
- The European Commission is also considering the benefits of introducing diesel with sulphur levels of less than 50ppm by 2005 and then lower (e.g. 10ppm) beyond 2005. Reducing the sulphur content further will enable more active emission reduction devices to be used. Note that off-road vehicles still use industrial diesel with sulphur content of 2000ppm (0.2%). Many cross-border vehicles also (legally) use mainland diesel with sulphur content of 2000ppm (0.2%). Government estimates 40% of diesel consumed in Hong Kong is high sulphur diesel.
- Synthetic or Fischer-Tropsch diesel can be made from natural gas. The diesel product is sulphur-free, has a high cetane number and very low aromatic level.
- Water-blend diesel is an emulsified diesel containing up to 20% water. Can be used directly in a diesel engine - reduces emissions of NOx and particulates. Reduces engine power.
- Various additives such as detergents or other substances can also be effective in reducing emissions on a short term and long term basis.

1 Common rail system allows independent control of injection pressure, timing and volume in response to engine operating conditions. This allows for reduction in engine noise and NOx emissions.
3 Already claimed to be competitive commercially with crude oil at $20/bbl or higher, and a few large investments worldwide in Africa, Malaysia and under development in the US. However it is unlikely that GTL clean fuels will become widespread within 10 years although smaller quantities will be available for blending. Histon P D (2001) Analysis and prediction of clean fuels in Asia. 2nd China/Asia Clean Fuels Conference 1-2 March 2001.
After-treatment devices

- Diesel particulate traps reduce emissions by filtering particulates from the exhaust stream. The collected particulates must be burnt or washed off. The Continuous Regenerative Trap (CRT) continuously oxidises diesel soot particles to CO\textsubscript{2}, thus regenerating the filter.

- Diesel oxidation catalysts reduce particulate emissions by oxidising carbon monoxide, gaseous hydrocarbons and liquid hydrocarbons adsorbed onto carbon particles in diesel exhausts to CO\textsubscript{2} and water. Very little effect on NO\textsubscript{x}. The US Environmental Protection Agency certifies DOCs with minimum particulate reduction efficiency of 25%.

- NO\textsubscript{x} control retrofit technologies are inherently difficult due to oxygen-rich exhaust of diesel engines and lack of sufficient reductants (mainly hydrocarbons) necessary to reduce the NO\textsubscript{x} to nitrogen. Most promising technologies to reduce NO\textsubscript{x} emissions include NO\textsubscript{x} storage catalysts which will enable diesel vehicles to meet Euro 4 standards for light duty vehicles. Selective catalytic reduction (SCR) and non-thermal plasma can reduce NO\textsubscript{x} by 80-90% but are not yet commercial.

Vehicle emissions

- ULSD reduces emissions of black smoke, particulates, hydrocarbons, carbon monoxide and carbon dioxide compared to standard diesel. In trials on a Euro I bus in Hong Kong, ULSD alone reduced particulate emissions by 89%\textsuperscript{5}. In conjunction with an oxidation catalyst, particulate and smoke emissions were reduced by 15-18%, though this is likely to be underestimated. Other tests done on higher sulphur diesel (0.2%) found DOC reduced smoke by up to 65% although clogging occurred on some bus models. The DOC remained effective even after 2 years service, reducing particulates by 37%.

- Particulate traps (locally developed) retrofitted to light duty vehicles reduced smoke by 30% for taxis, 35% for light goods vehicles and 21% for public light buses.\textsuperscript{6} However, if not cleaned daily, soot can build up and spontaneous combustion of the cartridge can occur.

- CRTs require the use of ULSD and Euro 1 or 2 engines to function properly but can reduce particulate emissions by up to 80%. In Japan, trials of CRTs on heavy duty vehicles and ULSD reduced particulates by 84-95% on some routes but failed on others. Particulate emissions increased when higher sulphur fuel was used thereby reducing the regenerative effect causing plugging of the filter is a problem, particularly for urban driving conditions.

- Using 10% water-diesel blend in a Euro II bus in London reduced emissions of NO\textsubscript{x} by 9% and particulates by 20% compared to ULSD.\textsuperscript{9} However, lowers exhaust temperature therefore may not be compatible with after-treatment devices.

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\textsuperscript{7} Hong Kong Polytechnic University (2000). Feasibility study of retrofitting low cost traps to in use light duty diesel (less than 4 tonnes gross vehicle weight). \textsuperscript{www.info.gov.hk/epd/} under air.

\textsuperscript{8} Yoshida M (2001). Outline and Outcomes of the Japan Clean Air Program. 2\textsuperscript{nd} China/Asia Clean Fuels Conference, Beijing. 1-2 March 2001.

Energy efficiency and Greenhouse Gas emissions
- Diesel engines are highly energy efficient and have lower life cycle greenhouse gas emissions (GHG) compared to petrol engines. However, both for light and heavy-duty vehicles diesel has higher life cycle emissions of GHG compared to other alternative fuels and vehicles.
- After treatment devices, such as EGR, reduce engine efficiency and increase emissions of GHG. No significant changes in lifecycle emissions are predicted for heavy duty vehicles using ULSD with a CRT.
- Reducing fuel sulphur consumes more energy in the refining process. Nonetheless, lifecycle GHG emissions for ULSD are only 1.6% higher than regular diesel.
- The Fischer-Tropsch diesel increases life cycle greenhouse gas emissions by an estimated 15%.

Impacts on vehicle performance
- ULSD reduces sulphur-induced corrosion and slows acidification of engine oil leading to lower maintenance costs. ULSD has lower lubricity, which can be enhanced by additives or oxygenate blends.
- Water-diesel blends reduce power (by equivalent water content). Reduced lubrication compared to diesel. Possible problems with water-diesel separation.

Costs
- While import price of ULSD higher due to extra refining required, tax concession for ULSD makes it competitive with regular diesel (which is no longer available at filling stations).
- Maintenance of diesel engines is very cost-effective although more regular, quality maintenance in Hong Kong is needed.
- Particulate traps for light duty diesel vehicles cost $1300 (fully subsidised by Government) but need daily washing which is time-consuming for operators. Moreover, operators lack convenient locations for filter washing and for disposal of particulate-laden waste water.

Table A1 Costs (HK$) of ULSD compared to standard diesel

<table>
<thead>
<tr>
<th>Diesel standard</th>
<th>Import price ($/L)</th>
<th>Duty ($)</th>
<th>Retail price ($/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regular diesel (350ppm sulphur)</td>
<td>1.81</td>
<td>2.00</td>
<td>5.99</td>
</tr>
<tr>
<td>ULSD (50ppm sulphur)</td>
<td>2.27</td>
<td>1.11</td>
<td>5.94</td>
</tr>
</tbody>
</table>

- Diesel oxidation catalysts for light duty vehicles cost $4000 (Government provides $1300 subsidy).
- CRTs for heavy duty vehicles cost HK$25,000-40,000

Infrastructure costs and requirement
- Existing infrastructure can be used. No modifications to diesel engines are required to use cleaner diesel fuels.

Safety
- ULSD poses no additional safety risks compared to conventional diesel.
- Carcinogenic.

12 ibid
13 Current diesel standard in Hong Kong is Euro 3 with sulphur content of 350 ppm (0.035%).
Availability

- Euro 2 & light duty Euro 3 vehicles widely available. Euro 3 buses to be introduced 1/10/01.
- ULSD is now available from refineries in Singapore.
- Particulate traps for small vehicles are produced locally.
- CRTs produced by Johnson Matthey. For buses, a similar trap, DPX, produced by Engelhard.
- Five manufacturers have oxidation catalysts certified by the US EPA to reduce urban bus particulate emissions by over 25%.  

Status worldwide and Hong Kong

- Diesel engines most commonly used engine worldwide for heavy trucks and buses. In Hong Kong over 150,000 diesel vehicles registered. Many of these vehicles are pre-Euro standard.
- Over 13,000 CRT particulate filters in service in Europe, the United States and the Far East.
- The 3 main franchised bus operators have, or plan to, fitted DOCs to their pre-Euro or Euro 1 bus fleet. They are also testing CRTs for operability and effectiveness. If successful they will retrofit CRTs to the bulk of their Euro 1 & 2 fleets.
- Government is testing 5 CRTs on Euro 1 & 2 vehicles and may fit more if tests are positive.
- First Bus is currently testing a diesel/water emulsion on 2 buses and may expand if the trial works well.

Applicability to Hong Kong

- Cleaner diesel fuels and technologies easily implemented since can be used immediately, with no infrastructure changes. Can be used by existing diesel vehicles.
- For the franchised bus operators who have many pre-Euro and Euro 1 buses, and for medium and heavy good truck operators, the use of cleaner diesel fuels with retrofit technologies offer a good short term solution.
- For cross-border vehicles, high sulphur mainland diesel would poison or clog many retrofit technologies such as DOCs and CRTs.

B. CLEANER PETROL

What is cleaner petrol?

- Petrol currently sold in Hong Kong is required to meet Euro 3 standards containing less than 150ppm sulphur, 42% aromatics, 1% benzene and no more than 0.005g/L lead). Since 1992 all new petrol engine vehicles are required to be fitted with a catalytic convertor.
- To meet Euro 4 standards for petrol vehicles in 2005, sulphur levels in petrol will be reduced to 50ppm and aromatics to 35%. The European Commission may reduce sulphur levels even further, although the vehicle and oil industry is divided on the benefits.
- New engine technologies, such as Gasoline Direct Injection (GDI) offer improvements in fuel economy. Advanced technologies, such as NOx storage traps, will also be used to meet future vehicle emission standards.
- Many countries encourage the use of oxygenates: high octane components that can reduce the aromatics content and lower emissions of carbon monoxide. Known as reformulated gasoline (RFG) in the US. Another oxygenate commonly used in the US but not in Hong Kong.

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15. See footnote 4.
MTBE, has been found to contaminate groundwater. Ethanol is being considered as an alternative.

**Vehicle emissions**
- Cleaner petrol formulations tend to have lower amounts of aromatics, olefins and benzene, all of which contribute to ozone and airborne toxins. However, some ethanol blends can be detrimental in terms of ozone formation (see section on ethanol).
- Emission tests conducted in the UK on light duty vehicle emissions using cleaner petrol show only marginal improvement in NOx and hydrocarbons and no change for carbon monoxide.\(^{16}\)

**Energy efficiency and Greenhouse Gas (GHG) Emissions**
- Reducing sulphur in petrol to 50ppm reduces N\(_2\)O (a potent GHG) by 60%.\(^{17}\)
- But sulphur reduction requires additional energy and increases fuel consumption during vehicle use. Lifecycle GHG emissions during refining and vehicle use are 2-3% more than those of conventional petrol.\(^{18}\)
- Cleaner grades of petrol will indirectly encourage new fuel economy measures such as GDI, which is predicted to reduce CO\(_2\) emissions by up to 15%.\(^{19}\)

**Performance**
- Performance would be slightly impacted due to generally lower energy density of oxygenates.
- Petrol oxygenated with ethanol can separate into phases if contaminated with water.
- Some cleaner petrol formulations can degrade natural rubber engine components.

**Costs**
- Vehicles do not require adjustments to use. Extends life of catalytic convertor.
- Cleaner petrol formulations tend to be more expensive due to additional processing. US EPA estimates that low sulphur petrol costs 0.75 US cents (HK$6) more per litre.\(^{20}\) In UK, duty differential of 3p/L (30 HKcents/L) provided as incentive for low sulphur petrol (50ppm S).

**Infrastructure Requirements and Costs**
- Cleaner petrol formulations can be distributed and stored in the same manner as conventional petroleum. Euro 4, once introduced, will replace conventional petrol at the filling stations.
- For additional blends with ethanol or other oxygenates, new tanks and dispensers would be required.

**Status of worldwide and in Hong Kong**
- RFG accounts for 25 percent of all petrol sold in the United States due to federal mandates to reduce air pollution and is, or will be, available in Italy, Germany, Sweden, Denmark and France to meet EU petrol standards. Hong Kong adopts EU specifications.
- Ultra low sulphur petrol (50ppm S) is widely available in UK.

**Availability and Applicability to Hong Kong**
- Hong Kong currently has no available source of cleaner petrol (ie low sulphur or oxygenated) formulations.

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\(^{16}\) See footnote 10.
\(^{17}\) See footnote 11.
\(^{18}\) Ibid
\(^{19}\) See footnote 10.
\(^{20}\) See footnote 11.
• The 355,000 licensed petrol vehicles and motorcycles in Hong Kong contributed over 57% of VOCs emitted by vehicles in 1997—creating a big market for cleaner petrol formulations.

C. LIQUEFIED PETROLEUM GAS (LPG)

What is LPG?
• A mixture of propane (C\textsubscript{3}H\textsubscript{8}) and butane (C\textsubscript{4}H\textsubscript{10}). Auto-LPG in Hong Kong same as for domestic purposes: 20-30% propane and 70-80% butane.
• Obtained from extraction of natural gas or as a by-product of oil refining.
• A gas at ambient temperature and pressure but stored as a liquid under moderate pressure (4-12 bar) in a closed system, so no fuel vapours are vented during filling or operation.
• Can be used in most vehicle types either in dedicated models or bi-fuel engines. In Hong Kong conversions are not permitted on safety grounds, other than those carried out by OEMs.

Vehicle emissions
• All emissions reduced compared to conventional diesel or petrol. Particulate emissions are virtually eliminated, and for heavy duty vehicles using high propane LPG, NOx is reduced by about 60%, and THC's by over 80% compared to diesel.\textsuperscript{21}
• Compared to diesel taxis, LPG taxis emit negligible particulates and smoke, 20-50% less hydrocarbons and NOx under idle test conditions.\textsuperscript{22}

Energy efficiency and Greenhouse Gas emissions
• LPG is about 30% less energy efficient than diesel. Lower energy density means fewer km per litre of fuel than petrol/diesel. The heavier tanks also add to fuel consumption. This is balanced by LPG's low carbon content.
• Life cycle emissions of greenhouse gases slightly better for diesel light duty vehicles and comparable or slightly better for diesel heavy trucks.\textsuperscript{23} \textsuperscript{24}

Costs
• Capital costs of new LPG vehicles are higher than diesel counterparts in Hong Kong market.
• Government is offering a $40,000 grant to replace diesel taxis by an LPG one before or during 2001. Same grant offered during 2002/2003 for diesel taxis newer than six years old.
• Operational costs of LPG taxis are lower than diesel. Government has capped the LPG cost at dedicated filling stations by a pricing formula.\textsuperscript{25} However, operators are concerned these subsidies are temporary.
• LPG taxis have lower or comparable maintenance requirements and costs to diesel taxis.

Infrastructure costs and requirements
• Hong Kong is developing an LPG filling station infrastructure but stringent safety requirements limit the possible sites available, especially on Hong Kong Island. At the end of

\textsuperscript{21} See footnote 10.
\textsuperscript{23} See footnote 10.
\textsuperscript{24} See footnote 11.
\textsuperscript{25} The land premium on dedicated LPG filling stations has also been waived to keep LPG prices artificially low. Until 31/1/02 the price at dedicated stations ranges from $2.01-2.04/L compared to $3.88/L at converted LPG stations.
2000, there were 5 dedicated LPG filling stations, 4 temporary filling stations, and 3 petrol cum LPG filling stations, which can support about 8000 taxis.

- 40 stations (300 LPG nozzles) planned by end of 2001 to provide for entire taxi fleet. By end 2002, capacity could support 24,000 LPG vehicles including light bus fleet.\(^{26}\)
- If LPG vehicle fleet expanded further (e.g. light goods vehicles), more (new) LPG filling stations and bulk storage capacity would be needed.

**Safety**

- More volatile, readily ignited and burns more intensely than diesel. In the event of spillage, tends to sink to the ground with danger of gas build up, leading to explosions.
- A major fuel leak from an LPG vehicle is much less likely than from a diesel vehicle, due to the greater structural integrity of the LPG tank and safety equipment.\(^{27}\)
- The very few accidents involving the fuel systems of gas vehicles which have occurred elsewhere in the world in the last 10 years, all involved converted LPG vehicles which are not allowed in Hong Kong.
- Accidents involving LPG taxis in Hong Kong have not caused damage to the fuel system.
- Vehicles with LPG tanks of over 65kg are currently not allowed to be driven through tunnels. In theory a detonation of a flammable vapour cloud, released from an LPG container in a tunnel is possible. Interim results of a consultancy study indicates it would be acceptable for vehicles with LPG tanks of 100kg (such as light buses) to be safely driven in tunnels.\(^{28}\)

**Performance**

- Low propane content (and hence octane number) means less power, particularly for larger vehicles such as public light buses or trucks.
- With a premium grade of LPG (95% propane) even big buses can run on LPG.
- Performance of LPG taxis found to be comparable to diesel taxis.\(^{29}\)

**Status worldwide and in Hong Kong**

- Over 4 million LPG vehicles currently operate in over 30 countries, including Italy, Mexico, the Netherlands, USA, Japan, Australia and South Korea.\(^{30} \)\(^{31}\) LPG with high propane content is also used for coaches, buses, garbage trucks and tow-trucks.
- Guangzhou retrofitted over 3,000 buses and taxis to use both petrol and LPG. Shanghai has also converted 25,000 of its 42,000 taxis to LPG.
- From 2001 onwards all new taxis in Hong Kong are required to use LPG. All Hong Kong taxis (about 18,000) will run on LPG by 2006. As of February 2001, 6,000 taxis were using LPG.
- Hong Kong will shortly complete a trial of 11 LPG and 4 electric buses public light buses. Subject to the outcome of the trial, some 6000 public light buses could be switched to LPG.
- Government will study whether LPG supply can service some 70,000 light goods vehicles.\(^{32}\)

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\(^{28}\) EMSD, Pers Comm

\(^{29}\) See footnote 22.

\(^{30}\) In 1997 2 million were in Europe, .7 million in Asia, .5 million in Australasia, .4 million in north america and .3 million elsewhere. www.worldlpg.com/auto/index.htm

\(^{31}\) See footnote 27.

\(^{32}\) EMSD, Pers. Comm.
Availability in Hong Kong

• Dedicated LPG taxis are currently available from Toyota, Nissan and Ford.\textsuperscript{33}
• LPG is currently imported from the Middle East or Singapore. Five LPG terminals at Tsing Yi, with a combined storage capacity of 15,000 tonnes (a 20-30 day supply but reduced to 10 days if all taxis and PLBs eventually are LPG which is insufficient on security grounds).\textsuperscript{34}
• The new LPG filling station operators propose to import LPG directly from China.
• Expanding supply further would require increased storage and barge landing capacity, and the necessary planning, environmental and risk studies.

Applicability to HK

• Hong Kong’s extensive investment in LPG infrastructure for taxis argues for extending the use to PLBs and, perhaps light goods vehicles, depending on the adequacy of LPG supply.
• Passenger vehicles also suitable, but loss in fuel duty revenue, and lack of LPG capacity may also limit this application. Since LPG offers few emission benefits over petrol vehicles, more sense to convert diesel vehicles.

D. ETHANOL

What is Ethanol?

• Ethanol (CH\textsubscript{3}CH\textsubscript{2}OH) is an alcohol oxygenate. Octane rating is higher than petrol, but cetane rating is lower than diesel.
• Produced from corn, barley or wheat, which is fermented and distilled into a pure (200 proof) product. Carbon dioxide is a significant by-product.
• Two common ethanol-petroleum blends to boost octane and reduce pollutant emissions: E-85 and E-10 (respectively 85% and 10% denatured ethanol).
• Ethanol-diesel blends (10% or 15% ethanol) recently developed with additives to improve stability.\textsuperscript{35}

Vehicle Emissions

• Compared to conventional petroleum, ethanol generally reduces toxic vehicular emissions associated with hydrocarbon emissions. However, use of ethanol blends can be detrimental in terms of ozone formation, due to the increase in total reactivity of VOC emissions.\textsuperscript{36}
• Compared to petrol, pure ethanol reduces CO by 30%, VOCs by 12%, and aromatics like benzene and toluene by 30%. Studies on NOx show either small (about 3%) increase or decrease. The amount of the reduction falls if less ethanol is used in the fuel.\textsuperscript{37}
• Ethanol-diesel blends lower CO by 15%, particulates by 13 % and smoke by 22% compared to diesel (0.05% sulphur). NOx emissions increase slightly by 0.75 %.\textsuperscript{38}

\textsuperscript{33} Ford’s 6-cylinder dedicated LPG Falcon Wagon taxi received type approval in Hong Kong. Ford has been producing dual fuel LPG Falcons in Australia for many years.
\textsuperscript{34} EMSD, Pers Comm.
\textsuperscript{35} Kenreck C, BetzDearbon. Presentation to EPD 17/10/00.
\textsuperscript{37} Alternative Fuels Data Center, “Ethanol General Information” and “Ethanol Vehicles”. http://www.afdc.doe.gov/afv/ethanol.html
\textsuperscript{38} See footnote 35.
Energy efficiency and Greenhouse Gas emissions
- Compared to petrol vehicles, pure ethanol-powered vehicles emit about 30 to 50 % less GHGs. Compared to passenger petrol vehicle, 85% ethanol blends can reduce lifecycle GHG emissions by 22% for ethanol from corn or 54% for ethanol from cellulose.  
- Alcohol fuels can achieve a high thermal efficiency when used in engines optimised to take account of higher octane number.

Performance
- Loss of power and fuel economy compared to diesel due to lower energy content.
- Pure ethanol vehicles compare well to petrol vehicles in terms of acceleration, payload, idling and cruise speed. Can be used directly in petrol cars with minor changes to carburetor. Lubricates better than petrol and raises cetane level.
- More difficult to start and stalls more—especially in colder climates
- Requires more frequent refuelling since one-fifth less energy than same volume of petrol,
- Can corrode some metals, gaskets and seals, requiring special (more costly) components.
- Water-soluble: susceptible to phase separation if water intrudes.

Costs
- Ethanol blends of 10-15% can be used directly in petrol engine—at nominal cost.
- Ethanol blends of 85% or more require special engines, tanks and components at extra cost.
- Ethanol costs in US$1.65/gallon (HK$3.4/L). Additional costs of 10-15% diesel-ethanol blends estimated to be HK$0.07-0.1/L.
- Due to water solubility, ethanol is typically shipped by rail, truck or common carrier pipelines which typically contain some moisture. That adds cost and logistical difficulties.

Safety
- Safer than petroleum. Biodegradable (water soluble) if leaks from storage tanks.

Status worldwide and in Hong Kong
- Brazil is largest producer and user: about 200,000 barrels per day for 5 million vehicles. The government guarantees producers’ minimum prices. 25,000 ethanol refueling stations.
- Sweden has 400 operating Scania ethanol buses. Mexico City will replace its 12,000 buses with Scania’s ethanol ones.
- Japan has 180 filling stations supplying an ethanol blend.
- Ethanol blends comprise 12% of fuel used in United States (about 125 billion gallons/year). Ethanol demand will increase by 2.3 billion gallons with phasing out of MTBE due to concern about its contamination of aquifers.
- Hong Kong’s EPD will trial reformulated gasoline, mixed with ethanol and oxydiesel (15% ethanol) based on availability of fuels and local interest.

Infrastructure Requirements
- Adaptation of existing refueling and distribution systems required for high percentage of ethanol blends.

Availability in and Applicability to Hong Kong
- No ethanol fuel producers or importers currently in Hong Kong. 40% of fuel consumed in Hong Kong (excluding buses) is petrol—good market for ethanol mixes.

39 See footnote 11.
China recently announced plans to increase ethanol production dramatically (estimates are as high as 50 million tons/year if excess vegetable matter used) to decrease pollution, satisfy demand for petroleum and increase energy security.\textsuperscript{40}

Several companies interested in producing ethanol in China and/or distributing ethanol and ethanol blends in Hong Kong: BioEnergy Technologies and Gaia Fuel. Estimated capital investment for a plant in China: US$100 million.

Fully appropriate for petrol vehicles—especially private cars. Trials on diesel/ethanol blends needed to assess performance and emission reduction.

E. BIODIESEL

What is Biodiesel?
- A liquid fuel, made from transformation of vegetable oils or animal fats. Similar physical properties and engine performance to petroleum diesel.
- Several possible sources for biodiesel: animal fats, virgin vegetable oils (including soy and rapeseed) and recycled restaurant cooking oils.
- Can be used as a fuel or mixed with diesel (usually 20% biodiesel) to reduce tailpipe emissions of key pollutants.

Vehicle emissions
- Contains approximately 11% oxygen by mass so produces less carbon monoxide and unburned hydrocarbons. Pure biodiesel most effective, but even biodiesel blends reduce most tailpipe emissions and proportionately to the amount of biodiesel used.

<table>
<thead>
<tr>
<th>Emission type</th>
<th>20% Biodiesel</th>
<th>100% Biodiesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particulate matter</td>
<td>Less 5 to less 15%</td>
<td>Plus 27 to less 68%</td>
</tr>
<tr>
<td>Total Hydrocarbons</td>
<td>Less 15% to less 20%</td>
<td>Less 37 to less 63%</td>
</tr>
<tr>
<td>Nitrogen dioxide</td>
<td>Plus 1% to plus 5%</td>
<td>Less 8 to plus 8%</td>
</tr>
</tbody>
</table>

Considerable divergence in literature as to amount of increase of nitrogen oxide emissions; appears to depend upon the testing methods. Adding a fuel additive or changing engine timing can curtail the NOx.

The University of Hong Kong, on behalf of the Government, is currently running emission trials on 10 different vehicle types using varying proportions of biodiesel (20% and 100%), and ULSD as a baseline. Results should be available in mid 2001.

Energy efficiency and Greenhouse Gas emissions
- Producing biodiesel from vegetable crops reduces upstream greenhouse gases (GHGs) since CO\textsubscript{2} is consumed in plant production. Overall lifecycle emissions of GHGs with biodiesel are lower than petroleum-diesel. Producing biodiesel from animal wastes or recycled vegetable oil also consumes CO\textsubscript{2} indirectly.
- Pure biodiesel and 20% biodiesel blends are estimated reduce lifecycle GHG emissions by 78% and 16% respectively compared to diesel (0.05%) sulphur.\textsuperscript{42}

\textsuperscript{40} 6/3/01 at National People’s Congress
\textsuperscript{41} Compilation of different studies. See footnote 11. See also US Department of Energy, Alternative Fuels Data Center website (afdc3.nrel.gov/afv/biodiesel).
\textsuperscript{42} NREL/TP-580-24772
Costs
- Hong Kong promoters estimate the pump price for biodiesel will be about $5-6/L (without duty) compared to $5.94/L (pump price with duty) for ULSD.
- If duty was imposed on biodiesel the price would be higher and uncompetitive with USLD.
- Can be used directly in standard diesel engines without any retrofitting.

Infrastructure Costs and Requirements:
- Could be stored and distributed through the existing diesel system if the oil companies agreed.
- If existing system cannot be used, new refueling stations required adding to overall costs.
- If biodiesel’s classification as a flammable good under the Dangerous Goods Ordinance could be changed (if deemed sufficiently safe) then garages could sell biodiesel like a fuel additive, such as motor oil.

Vehicle performance
- Better engine lubricant than petroleum diesel. Can be used directly in most conventional modern diesel engines.
- Slightly lower power, though depends on source of biodiesel.
- Can corrode natural rubber parts in older vehicles.

Safety
- Flash point of about 110 degrees C; about twice that of diesel so safer to handle and store.
- Contains no aromatics so less toxic than petroleum diesel. Completely biodegradable.

Status Worldwide and in Hong Kong
- Used in Brazil, Germany, Austria, the United States and France, and its production and use are increasing. The American Biofuels Association estimates that if biodiesel received subsidies comparable to the ones for ethanol, biodiesel would account for 8% of the United States diesel market.
- Both the United States (ASTM) and Germany have standards for biodiesel. The European Union is adopting standards. Hong Kong is considering its own standards: adoption of standards is a prerequisite to wide scale introduction here. Problems have occurred with fake ‘biodiesel’ sold to taxi drivers here in Hong Kong.

Availability in Hong Kong
- Several companies in Hong Kong are poised to market biodiesel here, if and when, the Government sets standards. Sunland Company imports rapeseed-based biodiesel from a German company, Oberland Mangold. Three others, Hednesford, Bioclear International and Dunwell International plan to use waste vegetable oil as their feedstock. Hong Kong restaurant owners currently spend $220 million to legally dispose waste oil at landfill.

Applicability
- As a blend with ULSD could help to improve emissions from in-use diesel vehicles further, especially pre-Euro vehicles.

F. BATTERY ELECTRIC VEHICLES
What is an electric vehicle?
• Battery Electric Vehicles (BEVs) draw electrical energy, stored in a battery on-board the vehicle, and convert it to traction by the use of an electric motor.
• Direct current (d.c.) motors are cheap, give high torque at low speed but efficiency and power are compromised. Alternating current (a.c.) motors have increased efficiency, twice the specific power but need for a controller (to convert dc to ac and regulate speed) adds to cost and complexity.
• Motors can be direct current (dc) or alternating current (ac). AC induction is powertrain of choice as allows use of brushless motors (easier to maintain) and have increased efficiency and twice the specific power.
• Most common batteries include lead acid, nickel-cadmium (Ni-Cd) and nickel metal hydride (Ni-MH). Lead-acid are most commonly used but have a relatively low energy density. Ni-Cd and Ni-MH have higher energy density, thus improving performance and range (110km for NiMH). However more expensive, and cadmium is highly toxic.
• No one battery or power train system has proved to be superior.

Vehicle emissions
• Emit no tail-pipe pollution but life-cycle emissions depend on method of power generation at the power station.
• Compared with a Euro II diesel single decker bus, life cycle emissions of CO₂, CO, NOx and THC are significantly reduced for a 12m electric bus in the UK.  

Energy efficiency and Greenhouse Gas emissions
• Considering only the vehicle itself BEVs are far more energy efficient than internal combustion engines (ICE). A BEV operates at roughly 46% efficiency, whereas an ICE achieve only 18% efficiency.
• Electric drive can recover up to 15% of potential and kinetic energy via regenerative electrical braking and in addition, BEVs use almost no energy when stationary
• Overall, BEVs have a lower global warming potential than conventional diesel and petrol vehicles.
• One Canadian study showed lifecycle GHG emissions of EV passenger cars to be significantly better than diesel although in Hong Kong emissions are likely to be higher.

Performance
• Higher initial torque and acceleration than internal combustion engines.
• Most modern EVs can have top speed of 90-120 kph and range of 90-150 km per complete charge. EVS produced for urban use have lower specification and performance.
• Drivers need to adjust driving style for maximum efficiency.

Costs
• Capital costs of BEVs are approximately 50-100% more than their conventional counterparts.

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43 See footnote 10.
45 See footnote 11.
46 See footnote 10.
• In Hong Kong BEVs are already exempted from First Registration Tax and enjoy nominal annual vehicle licence renewal fees.
• However, operating costs are estimated to be half the costs of diesel due to lower price of electricity and high efficiency of the vehicles. When lower operating costs are taken into account, BEVS can achieve comparable or lower lifetime (5-7 years) costs compared to diesel.

Infrastructure costs and requirements
• Electricity from any source can be used to recharge a BEV. For slow charging, grid electricity is used which is supplied at 220V a.c. For faster charging rates a higher voltage (11 kV or a 3-phase 380V standard industrial supply) is required.
• Recharging stations required for BEVs but relatively easy to install recharge points which can run off standard 220-volt wall sockets. The average battery pack can be recharged in 58 hours on 220 volts when fully empty.
• Fast charging only cost effective when multiple points are being considered for a site, eg at a fleet depot. These are able to recharge batteries to 80% in about 15 minutes. Need for thermal management critical.
• Alternatively, batteries can be recharged off the vehicle, and the whole battery pack swapped when flat.

Safety
• No flammable fuels therefore safer than conventional petrol and diesel vehicles.
• Utilise high voltages – wires and charging stations must be properly insulated.
• Safety of handling cadmium and lead would need to be addressed.

Status worldwide and in Hong Kong
• Currently more than 28,000 BEVs in Europe, which includes around 16,000 milk delivery vehicles in the UK, passenger cars, micro cars and other commercial vehicles. US Postal Office has the world’s largest fleet of 6000 BEVs.
• Most of the major motor manufacturers have developed BEVs, the more active include PSA Peugeot-Citroen, Toyota, Nissan, Ford and General Motors.
• Trial recently held in Hong Kong of electric minibuses on 4 routes – found to be technically feasible. One of the route operators has continued to use electric minibuses commercially.
• Companies supplying electric vehicles in Hong Kong include Vicmax and AEL.
• The Vicmax buses uses recyclable Ni-Cd batteries which are recycled in France. Batteries are recharged to 80% of capacity in less than 15 minutes or full capacity in 3 hours.
• AEL’s electric bus is used as Cathay staff shuttle at airport. This also uses a Ni-Cd battery and can travel 190km with 1 full charge plus 2 shorter charges.
• Hong Kong Electric has 6 BEV sedans and one 16 seater minibus. The latter is supplied by US firm Solecetria with a Goldpeak NiMH battery. Sedans recharge overnight from standard voltage. Minibus requires 10 hours at higher voltage.

Applicability to HK
• Best suited to predictable, regular routes of less than 160km per day, where significant stop-start driving in highly polluted areas. This would include: hotel and residential shuttles, school minibuses, corporate and government fleet vans, blood donation vans, mobile libraries, postal vehicles, and green minibuses.

47 See footnote 10.
G. TROLLEY BUSES

What is a trolley bus?
• Uses electricity from overhead wires to drive an electric motor, air conditioning and lighting.
• Moves on tyres rather than tracks, more flexible than trams.

Vehicle emissions
• As for Battery Electric Vehicles, pollution-free at street level (and quieter than diesel buses).
• Pollution generated at the power plant, but due to the greater efficiency of electric traction, emissions per passenger mile will be lower than a conventional diesel bus.

Energy efficiency and Greenhouse Gas emissions
• Highly energy efficient with 90% of energy utilised compared with 35% for a diesel engine.

Performance
• Good hill-climbing abilities due to better torque than diesel buses.
• With careful design the wiring system can allow for overtaking and bus -stop ‘leapfrogging’.
• Lack of route flexibility

Costs
• Capital costs of a trolleybus ($3.7 million) are 150% that of a diesel bus ($2.3 million) but offset by the longer lifetime of a trolley bus (25-30 years compared to 15 years for a diesel bus).\(^\text{48}\)
• Recurrent maintenance costs of vehicle low but overall maintenance costs would be higher.\(^\text{49}\)
• Operational costs slightly higher than diesel buses assuming current oil prices don’t rise and government doesn’t continue to rebate diesel duty to franchised bus companies.

Infrastructure costs and requirements
• Requires significant investment in overhead wires held up by metal poles or attached directly to building facades. The high current requires a relatively large cross sectional area of wiring.\(^\text{50}\) For short route costs could be $20 million upwards.
• Substations required to stepdown voltage. Can be compact (2m high, 2.5m wide and 4.6m long) and situated in car parks, under flyovers and on roof tops. Substation transforms 11kV ac supply to 600V direct current (dc).\(^\text{51}\)

Safety
• Overhead wires may impede fire fighting in narrow streets.
• Auxiliary traction batteries, or small internal combustion engine and generator could allow bus to go “offline” in emergency situations.

Availability
• Single -decker, 2 or 3 axle rigid chassis or 3-axle articulated versions available.\(^\text{52}\)

\(^{49}\) ibid
\(^{50}\) Transport Department (1999). A Case Study – Trolley Buses in Hong Kong. Unpublished internal study.
\(^{51}\) ibid
\(^{52}\) ibid
• No double deck trolleybuses produced at present but possible to produce using existing bus chassis. Hong Kong would need 3 axle double decker, with air conditioning and low floor.  

Status worldwide and Hong Kong
• In operation in over 340 cities in Asia, America and Europe, including 26 cities in China
• Citybus currently running a 6 month trial at Wong Chuk Hang on a converted short double deck Dennis Dragon bus to check reliability, durability, performance and costs.
• The Transport Department study on trolley buses due to be published in early 2001.

Applicability to HK
• Relatively short and busy routes most promising. Good for hilly routes and polluted urban areas in both Hong Kong Island and Kowloon.
• Urban route 98 (Lei Tung Estate to Aberdeen) has been suggested as an ideal trial route, which would require 6 short double deck trolley-buses.

H. HYBRID VEHICLES

What is a Hybrid Electric Vehicle?
• A Hybrid Electric Vehicle (HEV) combines two power systems in one vehicle: 1) an electric motor and battery, and 2) an internal combustion engine (ICE). Optimises advantages of both: convenience of ICE and approaching the zero tailpipe emissions of BEV. Overcomes problems of range and charging of pure BEV.

Figure A1: Series Hybrid

Figure A2: Parallel Hybrid

• Two types of hybrids exist.
• “Series” hybrids use a small ICE, operating at a constant speed, to charge the battery which in turn drives the electric motor. Advantages: Operates at optimum efficiency and emissions performance. Engine never idles. Disadvantages: larger, heavier battery than parallel hybrid.
• “Parallel” hybrids have both an ICE and battery-powered drivetrain, either of which can operate the car. The engine is smaller and tuned for optimal efficiency with the battery pack to provide extra power (for start-up, acceleration, etc).

54 See footnote 50.
from the electric motor. Advantages: tend to have more power and smaller battery than series or conventional BEV.

- No external recharging of battery required (although can be done). Require high power batteries such as nickel cadmium and nickel metal hydride.
- Regenerative braking in HEVs recovers energy (up to 20%).
- Hybrids commercially available now use petrol or diesel although other fuels (e.g. natural gas) can be used. Fuel cell hybrids will eventually be available.

Vehicle Emissions

- HEVs’ higher fuel efficiency reduces toxic and ozone forming pollutants dramatically.
- Honda’s Insight is an ultra low emission vehicle while the Toyota Prius is a Super Ultra Low one under California’s air quality rules.

<table>
<thead>
<tr>
<th>Emission reductions for hybrid passenger vehicles compared to petrol (US RFG) (% of change) (all sampling locations)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VOCs</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>41%</td>
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</tbody>
</table>

- Emission reductions for hybrid buses compared to diesel are even more dramatic. Hino Motors’ hybrid HIMR bus reduces NOx by 34%, particulates by 55%, black smoke by 56%. In tests, the Orion diesel hybrid reduces particulates by 50% and NOx by 33%. (reference)
- In Japan, hybrid bus for 56 passengers, reduced fuel use by 10-15%, particulates and black smoke by 55% and NOx by 34%.

Energy efficiency and Greenhouse Gas (GHG) Emissions

- Compared to conventional petrol vehicles, a petrol HEV can reduce GHG emissions by 35%. Compared to ULSD, a diesel hybrid passenger vehicle can reduce GHGs by 28%.
- A single decker bus diesel hybrid emits 40% less GHGs on a life cycle basis compared to a conventional ULSD bus. Diesel fuel hybrid most cost effective option for reducing GHGs.

Vehicle Performance

- Highly fuel efficient: 60 miles/gallon.
- Acceleration power: zero to 60 miles per hour in 11 seconds
- Quieter. More efficient power steering and air conditioning.

Cost

- More expensive than ICE. Prius costs as much as US$41,000 initially to produce but being sold for US$19995 in the US.
- Estimated increase in lifetime costs (without subsidies) of 22-37% for passenger car. Once HEV production is widespread, economies of scale could reduce costs.
- Cheaper operating costs due to about 30% better fuel economy. Over 10 years driving 15,000 miles year and paying US$1.20/gallon: net savings US$2500. Hong Kong’s higher fuel prices would increase net savings.

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57 See footnote 11.
Specialized mechanics required to maintain electric battery—at greater cost.

**Infrastructure Requirements and Costs**
- No new fueling infrastructure required.
- Increased electric maintenance and garages needed.

**Status worldwide**
- HEV cars, trucks and buses available with various fuels and fuel cells. Gasoline and diesel hybrids first to reach market.
- Toyota Prius has been sold in Japan since 1997, and now is sold in Europe and US. Honda’s Insight has same market. Other manufacturers, including Ford, GM, Renault, Audi, Daimler Chrysler, all introducing HEVs in near future.
- FirstBus, UK, converted a 20 seat diesel Mercedes-Benz bus into an HEV capable of operating as an electric bus 25% of the time.
- Orion Bus and Novabus Inc. are testing HEV diesel buses. Hino Motors is using diesel HEV bus in Japan for mountain roads. Hybrid buses also being used in Aalborg, Denmark and Genoa, Italy in urban centers.
- 50 HEV diesel buses are operating in Tennessee and Arizona by Advanced Vehicle Systems. Also 26 HEV buses operating in Denver, Colorado. New York Transit Authority has just ordered 250 HEV buses.
- Redbus’s diesel HEVs in Christchurch New Zealand will cost half of ICE diesel buses after amortizing 14 years of running costs.
- ISE Research Corporation will offer HEV heavy-duty vehicles, such as delivery and refuse trucks, refuse trucks, which reduce fuel use by 25-50% and all emissions by 50-95%.

**Safety**
- Petrol and diesel fuelled HEVs pose the same safety risks as ICEs.

**Availability and Applicability to Hong Kong**
- None of these vehicles are available from the official vehicle dealers in Hong Kong but, can be with government interest and sponsorship. Toyota has reportedly contacted the Government about introducing the Prius.
- No double-decker hybrid bus models available.
- Parallel hybrids better suited to urban/suburban routes where can switch to cleaner electric mode in city. Series hybrid better suited to urban driving conditions typical of Hong Kong.
- Best suited for passenger vehicles, light buses and light goods vehicles.

### I. NATURAL GAS (NG)

**What is natural gas?**
- NG is 80-99% methane (CH₄) gas, with small amounts of propane and other hydrocarbon gases, depending on the source. Liquefied natural gas (LNG) is almost 100% methane.
- Produced either from gas wells or in conjunction with crude oil production or from landfill gas or biogas.
- Can be used in an internal combustion engine (ICE), hybrid vehicle or fuel cell vehicle.
- Usually stored on vehicle as compressed natural gas (CNG) or liquefied natural gas (LNG).
- CNG stored onboard at high pressures in high strength steel or lighter composite cylinders, which require 2-4 times the space of a conventional diesel fuel tank for the same range.
• LNG stored at −160 degC in specially designed, insulated containers. Best suited for larger vehicles as higher energy density of LNG allows a longer range. Space requirements similar to diesel tanks.

**Vehicle emissions**
• Clean-burning fuel being the simplest hydrocarbon. The high octane number (130) allows a higher compression ratio which improves thermal efficiency.
• Requires no vaporisation, hence has lower idling speeds, better performance and a more complete combustion, which all help to reduce emissions.
• Some NG vehicles sold by Original Equipment Manufacturers (OEMs) already classed as Ultra Low Emission or Super Low Emission.

**Energy efficiency and Greenhouse gas emissions**
• Less fuel efficient in converted engines due to less efficient engines and additional weight of the CNG fuel tank. Should be no loss in fuel efficiency in engines designed for NG.
• Methane itself is a potent greenhouse gas (GHG). Studies show mixed results for NGVs contribution to GHGs compared to petrol. One UK study found reduced lifecycle GHG emissions compared to petrol in passenger vehicles, but comparable or slightly higher GHGs compared to diesel light and heavy duty vehicles.\(^{59}\)
• A Canadian study found lifecycle GHG emissions slightly better than ULSD counterparts for CNG passenger vehicles, LNG heavy duty trucks and CNG buses.\(^{60}\)

**Costs**
• Capital costs of NGV typically 15- 20% more than conventional diesel counterpart.
• No retail market for NG in Hong Kong. Fuel costs without duty estimated to be significantly lower than diesel, making operation of NGVs cost effective in many applications.
• Maintenance costs vary. Increased fuel system inspection, tune up costs and more expensive parts can increase costs. Since NG a cleaner fuel, engine wear is less than diesel.

**Infrastructure costs and requirements**
• Currently no infrastructure for storage and distribution of NG in Hong Kong.
• NG compressors are large and need to be noise insulated.
• Depot refuelling is best for large fleets. China Light & Power (CLP) may develop a small LNG facility to convert some of their piped NG to LNG and transport it to electric substations or fleet depots to supply CNG or LNG vehicles.\(^{61}\)
• Once a piped NG distribution system is in place, NGV refuelling could take place from converted petrol stations without underground tanks as is required for LPG, petrol and diesel. Additional costs involved to compress the NG and maintain compressor stations.
• Gas storage facilities would be required for fast-fill refuelling stations, which allow approximately 4 minutes for a 30kg fill.

**Safety**
• NG is non-toxic and lighter than air which means, if spilled, it will disperse quickly if adequate ventilation.

\(^{59}\) See footnote 10.
\(^{60}\) See footnote 11.
\(^{61}\) For CNG vehicles, the LNG is vaporised into NG before being admitted into the engine.
• Narrow flammability limits compared with conventional fuels, which reduces the risk of a flammable mixture occurring.\(^{62}\)
• Air tight, very strong containers reduce risk of rupture.

**Performance**
• Converted engines less efficient than diesel counterparts, particularly at part load due to reduction in compression ratio and throttling losses.\(^{63}\) For purpose built engines minimal loss of efficiency.
• In some cases, CNG bus engines and fuel systems found to be less reliable than components in diesel buses, though these tend to be converted engines.\(^{64}\)

**Status worldwide and in Hong Kong**
• Over 1.2 million NG vehicles (NGVs) in use worldwide in over 40 countries including Argentina, Russia, Italy, Canada and the US. In the region Malaysia, Australia and parts of China have active NGV programmes. The majority are conversions.
• All major car, truck and bus manufacturers have built dedicated prototype NGVs and many NGVs are directly available from the OEMs, though still in small numbers.
• In Hong Kong CLP Power plans a pilot NGV programme initially fuelled with CNG this year: a small sedan/saloon car, van and single decker gas-electric hybrid bus.\(^{65}\)
• Towngas now running a one year trial of a CNG light goods van (currently using bottled methane gas).\(^{66}\) Slow filling (8 hours) used.

**Availability**
• Globally distributed and substantially higher known reserves than petroleum fuels.
• NG in Hong Kong currently piped from Hainan and used at CLP’s Black Point gas-fired power station. CLP propose to use some of this gas for a small number of their fleet vehicles.
• Hong Kong also produces significant quantities of landfill gas (a mixture of methane and carbon dioxide) from its 3 strategic landfills WENT, SENT and NENT (530,000 m\(^3\) per day currently, 1.5 million m\(^3\) per day at peak in years 2011-2019\(^{67}\)) and 13 old landfill sites. Only some of the gas being used for on-site energy needs, nearly half is flared. The gas will need processing and cleaning before use in vehicles. Landfill gas utilisation schemes must obtain permission from EPD. Landfill gas is also a source of synthetic diesel (see Diesel section).
• A liquified natural gas (LNG) plant in Shenzhen, China, planned for 2005 will supply Hong Kong Electric (HKE) new gas-fired power plant on Lamma Island. Towngas will likely be another user for this gas.
• The extensive distribution network for Towngas\(^{68}\) could be used for NG in a common carrier system in future.\(^{69}\)

\(^{62}\) See footnote 11.
\(^{63}\) National Renewable Energy Laboratory Report. NREL/DR-540-27503 [www.nrel.org](http://www.nrel.org)
\(^{65}\) Charles Wong, CLP, Pers. Comm.
\(^{66}\) Sam Shum, Towngas, Pers. Comm.
\(^{67}\) Lawrence Lau, EPD, Pers Comm.
\(^{68}\) 49% hydrogen, 28.5% methane, 19.5% carbon dioxide and 3% carbon monoxide. [www.hkcg.com](http://www.hkcg.com)
Applicability to HK
- Most appropriate for heavy-duty vehicles including fleet operators, non franchised buses and delivery vehicles with own depot for overnight fuelling. Also suitable for franchised buses if filling speeds sufficiently fast.
- If landfill gas is utilised, refuse transfer/collection vehicles could be converted to CNG or LNG. If a filling station near the border is established, LNG vehicles could be used for cross-border traffic, depending on range. It is estimated 95% of cross border traffic operates within range of CNG/LNG fuelled vehicles.

J. FUEL CELL VEHICLES

What are Fuel Cell Vehicles (FCVs)?
- Fuel cells combine hydrogen and oxygen to produce water (reverse electrolysis). Chemical energy is converted directly to electricity with no combustion. Zero or extremely low emissions, depending on fuel used to produce hydrogen.
- Fuel cells are stacked to produce more electricity to operate FCVs. Each fuel cell generates over 1kW/L but adequate acceleration and speed for full-sized car requires about 50-65 kW or 150-200 cells at 350 watts. Weight and volume of fuel stacks can impair FCV function.

\[ H_2 + \frac{1}{2} O_2 \rightarrow H_2O \]

**Fuel cell types**

- Several fuel cell types but most FCV development using the Proton Exchange (or Polymer Electrode) Membrane Fuel Cell (PEMFC).
- PEMFC’s run on hydrogen—either pumped directly into the FCV or produced on-board (reformed) from hydrogen-rich fuels such as methanol, natural gas or gasoline.
- Providing fuel to the PEMFC is a complex technological problem. Its solution probably will determine how FCVs develop (see fuels below).
- Difficulties with fueling PEMFC led to development of Direct Methanol Fuel Cell (DMFC). No fuel processing is required. DMFC still experimental.

**Fuels for Fuel Cells**

**Hydrogen**

- Hydrogen can be used directly in PEMFC vehicles. Highest energy density of all fuels (120MJ/kg compared to 42MJ/kg for petrol).
- On board storage is required. A vehicle with fuel efficiency of 70 miles/gallon requires 200 liters of compressed hydrogen for 350 mile range. No technical solution to on-board storage in immediate future but hydrogen believed to be long term fuel choice.
- Despite its power density and efficacy, problems of hydrogen storage on board and lack of hydrogen infrastructure need to be overcome.

**Methanol**

- Liquid fuel made from any carbon source (natural gas, coal, landfill gas, sewage71). On board storage less problematic than hydrogen.
- Can be reformed at low temperatures either by steam reforming, partial oxidation or a combination of the two.72 Reformation produces CO which can deactivate the platinum catalyst in the fuel stack. Addition of a preferential oxidation reactor can eliminate the CO, but adds even more weight to the processor and loses H2.
- Direct methanol fuel cell (DMFC) being developed which does not use reformer, liquid methanol injected directly. Problems of poor performance and low fuel efficiency.
- EC and Japanese FCV development programmes focussed on methanol because easier to process and higher fuel efficiency than petrol.

**Petrol**

- Complex reformers required. However less efficient than methanol, and much less efficient than hydrogen. Produces more emissions than other FCV alternatives (but still runs 100 times cleaner than ICE cars).
- Development of “fuel-cell” grade petrol required. High amounts of sulphur and typical additives in regular petrol can contaminate the fuel stack.

**Vehicle Emissions**

- A hydrogen-powered FCV emits zero tailpipe emissions. Methanol or petrol FCVs emit traces of emissions from the reformer but far less than a similar petrol-fuelled ICE.
- Greater efficiency of FCV’s drive train and engine partly accounts for improved emissions.

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71 In Berlin, 33 million gallons/year is produced from gasifying dried sewage sludge.
**Energy efficiency and Greenhouse Gas emissions**

- No GHGs from hydrogen FCV during operation. Lifecycle emissions depend on method of hydrogen generation.
- Methanol from biomass consumes and produces GHGs. Natural gas (NG) produced methanol produces more GHGs than biomass-produced methanol.
- Petrol FCV GHG tailpipe emissions are half of ICE vehicles but higher than other FCVs.
- Compared to a conventional petrol passenger vehicle, fuel cell vehicles can reduce lifecycle GHG emissions by 39% (methanol), 53% (hydrogen from NG) or 85% (hydrogen from renewable power sources). However this is considered by one study to be the least cost effective way to reduce GHGs from vehicles.\(^7^3\)
- Compared to a single decker bus running on ULSD, fuel cell buses can reduce lifecycle GHG emissions by 24% (methanol), 40% (hydrogen from electrolysis) or 44% (hydrogen from NG).\(^7^4\)

**Costs**

- Conventional petroleum engine now costs US$2,000-3,000 (HK$16,000-23,000), a comparable prototype fuel cell stack costs about US$35,000 (HK$273,000).\(^7^5\)
- Fuel cell and car manufacturers both expect 10 fold drop in fuel stack prices over next decade with economies of scale. Economies of scale will also lower operating and maintenance costs to levels comparable with CNG within 20 years. Once FCVs are available, maintenance costs should be low due to simpler engine design and fewer parts.
- Fuel economy will be higher, so operating costs will be lower, irrespective of the fuel.
- Methanol in US cheaper than petrol but 47% higher costs per unit of energy.

**Infrastructure Requirements and Costs**

**Hydrogen**

- Cost of producing and distributing hydrogen in United States by 2030: US$230-400 billion and US$175 billion respectively (if FCVs get 80 miles/gallon of hydrogen) Per vehicle investment in hydrogen infrastructure: US$3500-5000, but higher if FCV fuel efficiency is lower.\(^7^6\) This assumes a hydrogen pumping network.
- Cheaper alternative: ship hydrogen-rich fuels (e.g. natural gas) in existing gas pipelines to end-users, with small-scale reformers to convert to hydrogen on-site.
- Stuart Energy Systems of Toronto, Ontario (partly owned by Cheung Kong Infrastructure) developing mini-hydrogen stations to deliver compressed, purified hydrogen from cheap hydropower into vehicles or for storage. Stuart’s estimated cost: about US$2.50-3.00/kg\(^7^7\)---similar to petrol.
- Interim solution before widespread conversion to hydrogen: Storage and distribution of compressed hydrogen in cylinders, like CNG is today.\(^7^8\) Directed Technologies estimates that compressed hydrogen, if untaxed, could meet price of taxed petrol (assuming vehicles operating with 24.5 miles/gallon) if the FCVs’ efficiency was 80 miles/gallon.

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\(^7^3\) See footnote 11.
\(^7^4\) ibid
\(^7^6\) Stork K et al. Assessment of Capital Requirements for Alternative Fuels Infrastructures. Argonne National Laboratory Report No. ANL/ESD/TM-140. *Source for all infrastructure costs on this page.*
\(^7^8\) AEA, 1999 in Cleaner Vehicle Taskforce (2000).
Methanol

- Methanol: worldwide production only about 26 million tons/year—less than 6% of petrol used in United States/year. Methanex, the largest world producer, plans to construct large plants, each sufficient to fuel 500,000 FCVs, for about US$700/vehicle.
- Petrol infrastructure could be retrofitted for methanol if oil companies willing. Cost for developing a delivery system in United States estimated US$350 million - 9 billion, or US$70-100/vehicle. Cost of full infrastructure in United States: about US$84 billion.

Gasoline

- Well-established world-wide infrastructure for distribution. Would need a separate pump for fuel cell grade petrol. Introduction of unleaded petrol serves as an example.
- Development of fuel-cell grade petrol involves additional cost and investment at refineries.

Safety:

- FCV safety depends upon the fuel used and how it is distributed and stored.
- Hydrogen more flammable, burns hotter and faster than petrol but without toxic fumes. If released, disperses much faster, reducing risk of fire.\textsuperscript{79}
- Methanol is toxic and highly odorous. Spills into water supply render the water unpalatable. Biodegradable. Harder to ignite than petrol and burns slower and cooler. Not carcinogenic.
- Natural gas and petrol—see separate sections.

Performance

- FCVs are largely experimental—performance testing is generally premature except for the Ballard Systems trial bus run in Vancouver and Chicago. Three FCV buses used in each city for 2 years, for 118,000 km, 10,599 hours on road and with 205,000 riders.
- FCV buses were quieter, weighed more and carried 3/7 fewer passengers. FCV buses accelerated equally to diesel buses from 0-20 mph, but slower from 30 and 40 mph.
- Due to system or coach break-downs, upgrade work and unexpected maintenance, in the shop almost half the trial period.

Status Worldwide and in Hong Kong

- FCVs are not commercially available anywhere. Major auto manufacturers are heavily investing in fuel cell vehicles (FCVs) development.
- 9 largest automobile manufacturers all have prototypes, usually with PEMFCs and methanol. Daimler Chrysler plans wide scale commercial sale of FCVs by 2004. GM hopes to have petrol FCV on sale by end of decade.
- 30 transit single-decker buses fuelled by compressed hydrogen will go on trial in 9 European cities in 2002 and 2003.
- By 2020, FCVs will comprise between 7 to 20 percent of vehicles worldwide, or some 40 million FCVs.\textsuperscript{80}

Applicability

- Long term solution for entire fleet. Transit buses and passenger vehicles likely to be first commercially available vehicles.

\textsuperscript{79} During the 1937 Hindenberg explosion (caused by atmospheric electricity igniting flammable substances coating the airship’s envelope), the hydrogen fuel ignited but did not explode. Hydrogen’s unique burning properties meant that the fire remained in the fuel compartment, without spreading far, limiting injuries.

\textsuperscript{80} American Methanol Institute. Beyond the Internal Combustion Engine. www.methanol.org