International Journal of Engineering Research and Development
e-ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 10, Issue 12 (December 2014), PP.29-35

Alternative Fuel Public Transport Buses

Kaustubh Dilip Patil, Prof. Firoj Umraobhai Pathan
Prof. Sunil M. Mahajan, Prof. D. R. Satpute.
Snadip Institute of Technology and Research Center, Mahiravani, Nashik.

Abstract:- The paper objective is to develop an analytical framework that will give us more insight into the trends in emissions standards as well as technology development, and eventually translate these insights into a sound investment decision making strategy. Public transport buses are high usage vehicles that operate in heavily congested areas where air quality improvements and reductions in public exposure to harmful air contaminants are critical. As such, they are good candidates for achieving both near-term and long-term emission reductions. Cleaner and less polluting public transport buses based on alternative fuels are of paramount importance if cities are to attain their ambitious emissions reduction targets. Decision making for the investment in alternative fuel buses is dependent on future technological development and emissions standards, and it is difficult, given the uncertainty in regards to both these factors.

I. INTRODUCTION

This paper establishes the importance of emissions standards and technological development during the decision making process of procurement of new public transport buses. The primary environmental objective of any city is to reduce human exposure to harmful pollutants while at the same time not hindering the movement of people. This objective can be achieved in two ways—reduce the number of vehicles and reduce the pollution from each vehicle. The number of vehicles can be reduced by improving public transport and simultaneously encouraging residents to use public transport instead of driving their personal automobiles. Pollution from each vehicle can be reduced by promoting the use of alternative fuel vehicles that have lower emissions. A bus has a life expectancy of about 20 years. If the emissions standards change during the lifespan of a bus and if it can no longer satisfy the requirements, the bus has to be phased out or upgraded to comply with the emissions standards requirements—which cost time and money, thus leading to financial and service losses Given the potential of alternative fuels as a clean and safe energy resource, they can be expected to play a larger role powering the transport sector in the future. Cleaner and less polluting public transport buses based on alternative fuels are of paramount importance if cities are to attain their ambitious emissions reduction targets, as public transport buses are high usage vehicles that operate in heavily congested areas where air quality improvements and reductions in public exposure to harmful air contaminants are critical. The objective of a decision maker while investing is to optimize the returns of his/her investments—low costs for high returns. Given the long life span of the buses, a decision maker is faced with a number of uncertainties while making the investment decision. As such, they are good candidates for achieving both near-term and long-term emissions reductions, as many buses are centrally kept and fueled, making the introduction of new technologies and alternative fuels more efficient These uncertainties are related to the progression of the technology development and emissions standards for diesel buses, i.e., the pace at which they will become more stringent and the development of technology over time. Numerous strategies can be employed to face this uncertainty including delay of decision, do further research, implement a robust solution, implement a flexible solution, take incremental steps by implementing a solution that builds on the existing competencies etc.

II. ALTERNATIVE TECHNOLOGIES

Among the niche markets for alternatives that have developed, compressed natural gas (CNG) vehicles account for approximately 0.5% of vehicles worldwide, hybrid electric vehicles (HEVs) account for about 0.5%, and vehicles running on bio fuels account for less than 1% of transport fuel consumption. Smaller commercial markets exist for wholly electric vehicles and those fuelled by liquefied petroleum gas (LPG) and Fischer-Tropsch diesel made from coal and gas. Still other possible combinations include plug-in hybrids and hydrogen fuelled hybrid vehicles, not yet commercialized.

Toyota was first in the market with hybrid vehicles that have both gasoline engines and rechargeable electric batteries. This combination provides energy for urban ‘stop & start’ driving and is thus more energy efficient and less polluting. Other automobile manufacturers have now entered this market and hybrid technology is being diffused across a wide range of models. Some governments in the North offer tax credits for the purchase of these higher priced hybrid vehicles and it is expected that their share of domestic markets in these countries will rise. Toyota has announced that a hybrid car plant will be built in China to meet expected demand there.

III. OVERVIEW OF ALTERNATIVE FUEL TECHNOLOGIES FOR BUSES

There are numerous alternative fuel technologies for public transport buses available in the market; most notable are clean diesel buses, compressed natural gas (CNG) buses, hythane buses, hybrid buses and fuel cell buses powered by pure hydrogen (AATA 2002; WSU 2004). In this section, we discuss, compare and contrast these technologies.

CNG Buses

Consisting primarily of methane and other light hydrocarbons, natural gas does not contain hydrocarbons that form harmful emissions.Natural gas (NG) has been proposed as a much cleaner alternative to conventional diesel. In fact, the principal source of particulate emissions from natural gas vehicles is the combustion of lubricant. Replacing heavy-duty diesel vehicles with CNG equivalents is one option for reducing vehicular particulate emissions dramatically. Many cities have started investing in CNG buses. For example, cities such as Mumbai and Delhi have completely shifted their fleet from diesel buses to CNG buses (Yedla and Shrestha 2003); for cities in developing countries such as India, CNG buses offers low emissions and cost-effective public transport. Alternative transport fuel markets are typically built on the foundation of existing industries and other fuel applications. LPG and natural gas, for example, are typically used as domestic or industrial power sources before they are adopted for transport. Pakistan’s CNG vehicle system grew out of longstanding efforts to develop the county’s gas resources, which have been used since the 1950s. Pakistan has a well integrated gas infrastructure (approximately 50,000 km of distribution and service lines) and while the vehicle programmeis one of the largest, transport is still a small player in the country’s gas markets.According to the Ministry of Petroleum and Natural Resources 45% of natural gas consumption in 2003 went to power, 18% to fertilizer, 18% to general industry, and 2% to transport. Biofuel programmes also typically redirect existing agricultural and industrial production processes to the transport sector, building on established agricultural industries in sugarcane, palm oil and so forth. South Africa has recently used ethanol production capacity in the pharmaceutical industry to supply ethanol as a substitute for lead additives in gasoline.

Hythane Buses

Hythane, a patented product, is a mixture of 20 percent by volume of H2 and 80 percent methane (Hythane 2007). The laboratory for Transport Technology at University of Gent in Belgium has done considerable research on the suitability of hythane for public transport buses. In its experiment, a city bus with an adapted MAN CNG engine was tested on a chassis dynamometer at four speeds (30, 50, 70 and 80 km/h) with natural gas and hythane (HydroThane 2004). The same load conditions at the same speed were realized for the two fuels so that exhaust emissions concentrations can be compared. The averages over the four speeds of the exhaust gas concentrations with hythane as a fuel compared to natural gas are 66 percent reduction of unburned hydrocarbons (HC), 32 percent reduction of nitrogen oxides (NOx), 17 percent reduction of carbon monoxide (CO), and 13 percent reduction of carbon dioxide (CO2). Experiments at the University of Lund and City of Malmo gave similar results for hythane (Ridell 2005). CNG buses are looked upon as a potential alternative to diesel buses – they are less polluting and the fuel is widely available. However, in an effort to reduce their pollutants further, CNG buses can be converted to run on hythane (Bauer and Forest 2001). Mixtures of hydrogen and natural gas are considered viable alternative Fuels to lower overall pollutant emissions but suffer from problems associated with on-board storage of hydrogen, resulting in limited vehicle range (Nagalingam et al.

1983). There are many cities in the world that are experimenting with hythane, such as the Beijing Hythane Bus Project, whose demonstration phase will be to adapt 30 natural gas engines for hythane operation (Ortenzi et al. 2007). An emerging alternative to conventional diesel engines is electric hybrid bus technology. Hybrid buses typically use an electric drive coupled in series or operating in parallel with a combustion engine and traction battery. Hybrid technology allows the use of a smaller internal combustion engine that is designed to operate near its optimum efficiency, thereby minimizing engine emissions and maximizing fuel economy. Typically, a hybrid system also employs regenerative braking, which transforms kinetic energy into electric energy, again improving fuel economy. To a fleet operator, hybrid technology is attractive because it does not require the development of new refueling infrastructure or modifications to existing maintenance areas (WSU 2004; Tzeng et al. 2005).

Clean Diesel Buses

There have been tremendous innovations in diesel engine technology over the past few years—for example, advanced engine electronic combustion control, fuel injection systems and turbochargers to optimize performance and lower the emissions (Gifford 2003). Advanced low-sulphur fuels are available in the market. These cleaner diesel fuels produce lower emissions and enable advanced emissions treatment systems (catalysts and filters). Lower amount of sulphur in diesel fuel enables catalytic converters to be used, which, in turn, lower carbon monoxide (CO), nitrogen oxide (NOx) and hydrocarbon (HC) emissions. Emissions treatment such as particulate filters and oxidation catalysts reduce emissions of ozone-forming compounds (NOx and HC) and trap and eliminate particulate matter (PM) (Gifford 2003; Kassel and Bailey 2004). Currently, diesel emissions are reduced by turbo-charging, after-cooling, high pressure fuel injection, retarding injection timing and optimizing combustion chamber design. Turbochargers reduce both NOx and PM emissions by approximately 33 percent when compared to naturally-aspirated engines. Combustion chamber improvements and air-fuel injection advancements are ongoing in the industry and result in improved fuel economy and emission reductions (WSU 2004). As diesel engine improvements have already reached their limit, NOx and PM emission control requires after treatment devices to satisfy new, stringent emissions standards.

Fuel Cell Buses

Fuel cells reverse the long known process of electrolysis, which uses energy to split water into its components. Instead fuel cells use a fuel supply to combine hydrogen and oxygen thus generating an electric current. In the proton exchange membrane (PEM) fuel cells that are the current focus of research in applications of this technology in the transport sector, the process is electrochemical and involves an ion exchange polymer membrane as the electrolyte and electrodes of a fine metal mesh on which a platinum catalyst is deposited. The PEM fuel cell can thus convert hydrogen directly into electricity without combustion or moving parts. In hydrogen fuel cell vehicles (HFCVs) the process is virtually pollution free. But the overall utility of HFCVs in reducing greenhouse gases globally depends upon the way the hydrogen itself is produced. If this takes place through renewable processes that are carbon neutral such as coupling solar or wind power to electrolysers that split water molecules into hydrogen and oxygen, the overall impact will be significant. But technologies such as these are only now being developed and tested and they face challenges concerning cost and efficiency. Currently the most common and cost effective way to produce hydrogen is through natural gas steam reforming.

Table 1. Comparison of Different Alternative Fuel Technologies

Criteria	Clean Diesel	CNG	Hythane	Hybrid	Hydrogen/ Fuel Cell
Purchase Price (AUD)	@600,000	@700,000	@700,000	@1,300,000	@2,000,000
Fuel	Fuel is easily available	Can use existing fuel infrastructure.	Can use existing CNG infrastructure.	Can use existing fuel infrastructure.	Lack of fuel and fueling infrastructure.
Emissions	Higher emissions	Reduced emissions compared to diesel.	Reduced emissions compared to CNG.	Lower emissions.	No tailpipe emissions.
Technology	Mature technology	Old technology with new application.	Minor modifications to CNG technology.	New technology - unproven service record.	Technological barriers still to be overcome.
Safety	Most stable fuel	Natural gas stored in high pressure cylinders – high potential for leaks, explosion.	Natural gas and hydrogen stored at high pressure – potential for leaks and explosion.	Diesel is a stable fuel, but electric motor drive system presents potential for electrocution.	Hydrogen is stored in high pressure cylinders – high potential for leaks and explosion.
Performance	Proven service record	Limited range of operation.	Limited range of operation.	Flexibility due to dual power system.	Unproven technology and unknown durability.
Summary	Stable fuel, proven technology but higher emissions	Low emissions and proven technology. More expensive than diesel.	Very low emissions – combines strengths of natural gas and hydrogen.	Low emissions, but new technology and expensive.	Lowest on road emissions but unproven tech and very expensive.

IV. LEARNING ABOUT ALTERNATIVES

The rapid rise of private automobiles in developing countries has contributed to economic growth and expanded mobility, it has also resulted in negative impacts on public health, the environment, and urban liveability and energy costs.The vast majority of vehicles in the world (more than 95% of the world market) are currently based on spark ignition or compression ignition propulsion technologies using gasoline or diesel fuel.. But is this an inexorable outcome of the industrialization and urbanization process, or can new thinking and new technologies enable these countries to set different priorities and make technological choices that lead to movement down more sustainable paths? Hydrogen and fuel cell technology are one combination from among a range of established and emergent fuel and power train options to consider (Table 1). The total number of fuel cell vehicles worldwide is about 600 and these are prototypes serving as test vehicles. There is thus a need to evaluate alternatives for the transport sector at least as partial solutions to the problems of energy efficiency, urban pollution, and greenhouse gas emissions in the short and medium term. Although hydrogen and fuel cells are often identified as the ultimate, technological combination for the long term, decision-makers, in reality, are now faced with a complex range of options, in which the costs and benefits of different approaches are dependent on local resources, policy goals and strategic approaches. In this sense, the merits of different technologies will be shaped by specific, national decision making contexts, social and economic goals and concerns about future lock-in situations that may be created by the adoption of alternatives for the short and medium term that involve heavy infrastructure and other expenditures. Despite the complexity and uncertainties in approaching these choices, there are already lessons to be learned from a diverse range of alternative transport initiatives in developing countries. These examples illustrate how the first steps can be taken and how transitional niche markets tend to develop. The brief discussion below emphasizes the importance for decision-makers when approaching these various options to consider the nature of domestic energy resources, the specific public policy measures that are required, the related industrial capabilities already in place, and the nature of pressing social concerns.

Emissions from diesel buses and emissions standards

Emissions from diesel engines are the byproducts of the combustion of the fuel. As per a British Petroleum (BP) fact sheet, for every 1kg of diesel burned, there is about 1.1kg of water (as vapor/steam) and 3.2kg of carbon dioxide produced. Unfortunately, as there is no 100 percent combustion, there is also a small amount of byproduct of incomplete combustion: carbon monoxide, hydrocarbons, and soot or smoke. In addition, the high temperatures that occur in the combustion chamber promote an unwanted reaction between nitrogen and oxygen from the air. This results in various oxides of nitrogen, commonly called NOx (BP 2002). Figure 2 shows the composition of different gases in diesel engine exhaust. Exhaust from the public transport buses typically contains:

• Particulate matter (PM) – soot
• Nitrogen oxides (NOx) – lung irritant and smog.
• Carbon monoxide (CO) – poisonous gas
• Hydrocarbons (HC) – smog
• Carbon Dioxide (CO2) – Greenhouse gas

Particulate matter is the general term for the mixture of solid particles and liquid droplets found in the air. Particulate matter includes dust, dirt, soot, smoke and liquid droplets. It can be emitted into the air from natural and manmade sources, such as windblown dust, motor vehicles, construction sites, factories and fires. NOx emissions produce a wide variety of health and welfare effects. NOx can irritate the lungs and lower resistance to respiratory infection (such as influenza). NOx emissions are an important precursor to acid rain that may affect both terrestrial and aquatic ecosystems. CO is the product of the incomplete combustion of carbon-containing compounds (Cohen 2005). CO contributes to green house gas effects and global warming. HC comprises unburned hydrocarbons in the fuel; it contributes to smog (blue haze over heavily populated cities). Although CO2 emissions are more than 75 percent of the total emissions, and it is a green house gas (GHG) and has a huge global warming potential, it is still not mandatorily regulated by emissions standards. This will be elaborated further in the next section.

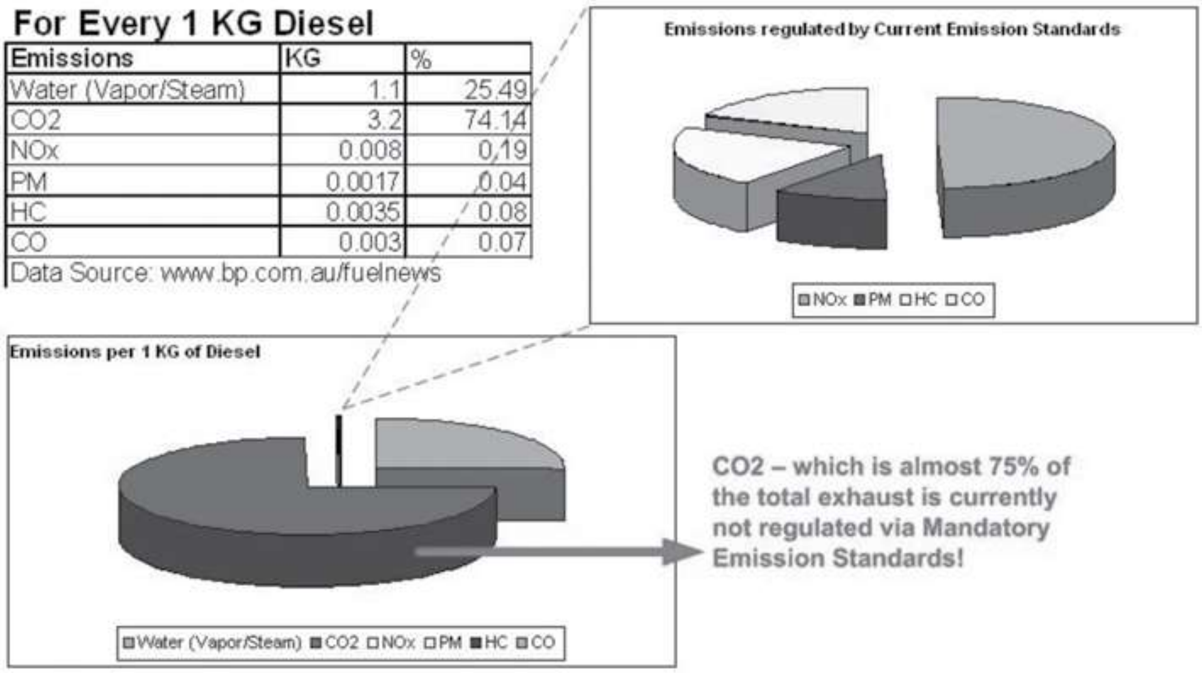

Figure 2. Exhaust from diesel buses

Social and political support is required

Alternative fuels typically evolve as key solutions to pressing social problems and are undertaken as social and political movements, as well as technological innovations. The introduction of electric three wheelers in Nepal was accomplished during a period of intense objection to air pollution from 3-wheeled diesel vehicles. Protests in Kathmandu prompted a ban on the diesel vehicles, making way for electric 3-wheelers. Urban air pollution was also a key driver of natural gas conversions in Delhi, where non-governmental organisations were instrumental in promoting a Supreme Court decision to convert bus, taxi and 3-wheeled vehicle fl eets in the city. Promoting rural and community based development is another driver that has become the explicit intention for a number of biofuel development projects. Building on lessons learned with ethanol, Brazil's ProBiodiesel programme has developed measures to enhance social inclusion and promote more equitable ownership and development of the biodiesel market. Provisions include tax incentives for "family agriculture" as well as preferential treatment for harvests that earn "social fuel stamps" that certify the regional distribution of biodiesel crops. Greenhouse gas emissions and climate change concerns are beginning to serve as social drivers of programmes, particularly for bio-fuels.

Access to Energy support is required

Not surprisingly, countries that have deployed significant alternative fuel programmes typically employ alternative fuel types or feed-stocks found in the country. Pakistan, Argentina, Egypt and Iran, for example, possess significant natural gas resources to fuel local natural gas vehicle programmes. Similarly, countries that have launched bio fuel initiatives usually have suitable climatic and soil conditions for sugarcane, rapeseed, soy, jetropha, among others. Of course, international oil prices also factor heavily into the viability of an alternative fuel programme, as demonstrated by the ebb and flow of the Brazilian ethanol programme, which has mirrored international oil prices in both its periods of development and decline. The advantages of alternative fuels over oil are often particularistic. Electric vehicles are viable in Kathmandu, Nepal, for example, due in part, to nearby hydropower resources, the practice of re-powering vehicles during non-peak hours and the relatively short distances travelled per day. Natural gas vehicles in Iran are made more attractive by the fact that the country lacks sufficient capacity to refine its crude oil. Recent efforts to blend ethanol with gasoline in India have been more problematic, in part because of poor monsoons, whose rains are needed to irrigate sugarcane crops in that country. Despite being the fourth largest ethanol producer in the world, India has been forced to import ethanol from Brazil.

Government support is required

The state plays an instrumental role in promoting alternative transport programmes. Governments support research, development and demonstration, provide coordination and leadership, develop new codes and standards, raise public awareness and create new markets through pricing support or regulatory support for alternative fuels and vehicles. Fuel taxation is a particularly important instrument through which the government can support alternative transport markets. Differentiated fuel taxes have been used to support CNG vehicles, as well as biofuel programmes. Recent efforts to support gasoline ethanol blends in Thailand have included tax incentives for both motorists and ethanol producers.

V. CONCLUSION

Looking at the trends in emissions, it is observed that the aggregate amount of PM, NOx, CO and HC (mandatorily controlled by emissions standards) in the air due to transport has reduced over the years and is forecasted to further reduce, in spite of increases in number of vehicles. The framework developed in this paper gives insight into the interactions between the actors, rules and technology components of the transport sector and highlights the way policies affect technology development and actor decision making. Due to the uncertainties about future policy rules, the decision makers should take incremental steps (build on the existing competencies) to safeguard investments. If the government aims at accelerating the diffusion of alternative fuel technologies, it should create a stable policy framework. Such a policy framework would give an idea to the decision makers about the future progression of rules and regulations. As seen from the case study, voluntary agreements to reduce CO_2 have so far been unsuccessful; future emissions standards should aim at mandating CO_2 emissions. Although decision making for the procurement of new buses is an important issue for transit authorities to achieve future environmental targets, little research has been done to date to assist the fleet manager in making these procurement decisions. The decision making process outlined in this research, based on forecasting, trend analysis and technology assessment, is adaptable to other types of infrastructure decisions to enable strategic procurement. Future research should be more comprehensive and could build on the analytical framework discussed in this paper to develop a decision making tool for the benefit of public transport authorities.

REFERENCES

[1]. AATA. 2002. Alternative fuels, emissions & technology. White paper. Ann Arbor, Ann Arbor Transportation Authority. Bauer, C. G., and T. W. Forest. 2001. Effect of hydrogen addition on the performance of methane-fueled vehicles. Part I: Effect on S.I. engine performance.

[2]. *International Journal of Hydrogen Energy* 26(1): 55-70.

[3]. Bauer, J. M., and P. M. Herder. 2009. *Designing Socio-Technical Systems. Handbook of the Philosophy of Science*. Meijers, Elsevier. BP. 2002. Diesel engine emissions. www.bp.com.au/fuelnews.

[4]. Clark, N. N., and F. Zhen et al. 2007. *Transit Bus Life Cycle Cost and Year 2007 Emissions Estimation*.

[5]. Washington, D.C., U.S. Department of Transportation Federal Transit Administration. CleanAirNet. Advanced diesel bus. Clean Air Initiative. Cohen, J. T. 2005. Diesel vs. compressed natural gas for school buses: A cost-effectiveness evaluation of alternative fuels. *Energy Policy* 33(13): 1709-1722.

[6]. CUTE. HyFLEET - Clean urban transport for Europe. www.global-hydrogen-busplatform.com/About/History/CUTE.

[7]. DieselNet. Emission standards. www.dieselnet.com/standards/.

[8]. DOE 2002. Alternative fuels in public transit: A match made on the road. Department of Energy, USA (Office of Scientific and Technical Information).

[9]. DOTARS. Australia design rules - Vehicles and the environment. www.dotars.gov.au/roads/motor/design/adr_online.aspx.

[10]. DOTARS. 2004. Regulation impact statement for vehicle emissions and fuel quality standards for the post 2006 period. Department of Transport and Regional Services on behalf of Land Transport Environment Committee.

[11]. Gifford, K. 2003. Advances in diesel engine technology. Clean Diesel Conference, Denver, Diesel Technology Forum.

[12]. Hao, J., and J. Hu et al. 2006. Controlling vehicular emissions in Beijing during the last decade. *Transportation Research Part A: Policy and Practice* 40(8): 639- 651.

[13]. HydroThane. 2004. Clean Technology for Public Transport (CTPT) - Hydrogen as a renewable alternative for diesel and gasoline.

[14]. Hythane. 2007. Hythane - Blue Sky, Clean Air. www.hythane.com/.

[15]. Karim, G. A., and I. Wierzba et al. 1996. Methane-hydrogen mixtures as fuels. *International Journal of Hydrogen Energy* 21(7): 625-631.

[16]. Kassel, R., and D. Bailey. 2004. Cleaning up today’s dirty diesels – Retrofitting and replacing heavy duty vehicles in the coming decade. National Resources Defense Council.

[17]. Kim, Y. J., and G. L. Sanders. 2002. Strategic actions in information technology investment based on real option theory. *Decision Support Systems* 33(1): 1-11.

[18]. Kojima, M. 2001. Breathing clean - Considering the switch to natural gas buses. World Bank Technical Paper. Washington, D.C., World Bank.
[19]. Meijer, I. 2008. Uncertainty and entrepreneurial action. The role of uncertainty in the development of emerging energy technologies. Utrecht, Netherlands, Utrecht University.
[20]. Meijer, I. S. M., and M. P. Hekkert et al. 2007. How perceived uncertainties influence transitions: The case of micro-CHP in the Netherlands. *Technological Forecasting and Social Change* 74(4): 519-537.
[21]. Nagalingam, B., and F. Duebel et al. 1983. Performance study using natural gas, hydrogen-supplemented natural gas and hydrogen in AVL research engine. *International Journal of Hydrogen Energy* 8(9): 715-720.
[22]. Ortenzi, F., and M. Chiesa et al. 2007. Experimental tests of blends of hydrogen and natural gas in light duty vehicles. HYSYDAYS - 2nd World Congress of Young Scientists on Hydrogen Energy Systems, Turin.
[23]. Ottens, M., and M. Franssen et al. 2006. Modelling infrastructures as socio-technical systems. *International Journal of Critical Infrastructures* 2(2/3).
[24]. Ridell, B. 2005. Malmo hydrogen and CNG/hydrogen filling station and Hythane bus project. Risoe Energy Conference, Roskilde, Denmark.
[25]. Scheinberg, P. 1999. Mass transit - Use of alternative fuels in transit buses. Report to Congressional Committee. Washington, D.C., United States General Accounting Office.
[26]. Schulte-Braucks, R. 2006. European vehicle emissions regulations. European Natural Gas Vehicles Association Conference, Brussels.
[27]. Tzeng, G.-H., and C.-W. Lin et al. 2005. Multi-criteria analysis of alternative-fuel buses for public transportation. *Energy Policy* 33(11): 1373-1383.
[28]. Walker, W. E., S. A. Rahman et al. (2001). Adaptive policies, policy analysis, and policy-making. *European Journal of Operational Research* 128(2): 282-289.
[29]. Walsh, M. P. (2000). Vehicle Emission Trends. Paris, European Conference of Ministers of Transport.
[30]. Weijnen, M. P. C., and P. M. Herder et al. 2008. Designing complex systems: A contradiction in terms. In Eekhout, M., R. Visser and T. Tomiyama, *Delft Science in Design², A Congress on Interdisciplinary Design* 3: 235-254.
[31]. WSU. 2004. New engine technologies: Diesel emissions reports. Olympia, Washington, Washington State University - Energy Program.
[32]. Wüstenhagen, R., and M. Wolsink et al. 2007. Social acceptance of renewable energy innovation: An introduction to the concept. *Energy Policy* 35(5): 2683- 2691.
[33]. Yedla, S. and R. M. Shrestha. 2003. Multi-criteria approach for the selection of alternative options for environmentally sustainable transport system in Delhi. *Transportation Research Part A: Policy and Practice* 37(8): 717-729.