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Overview

On November 7–9, 2005 the United Nations University held an international conference in Maastricht on "Hydrogen Fuel Cells and Alternatives in the Transport Sector: Issues for Developing Countries". The purpose of the conference was to raise awareness of emergent hydrogen and fuel cell technologies and to enhance long-term transport and energy decision-making in developing countries.

The conference brought together 35 leading experts from business, government and research organizations in the North and South to review progress in the application of hydrogen and fuel cells in the transport sector and identify key issues for developing countries. This brief summarizes some of these issues and the policy implications. The conference papers can be downloaded from the Hydrogen Fuel Cell Exchange Website at www.merit.unu.edu/hfc.

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Hydrogen Fuel Cells and Transport Alternatives: Issues for Developing Countries

RECENT TECHNOLOGICAL ADVANCES IN THE application of hydrogen fuel cells in the transport sector have drawn considerable attention and increased funding from both public and private sources over the past ten years. The International Energy Agency estimates that about US$1billion per year is currently being invested in public hydrogen and fuel cell research, development, test vehicles, prototype refuelling stations and demonstration projects, as compared to the total annual public budget for energy research, development and demonstration of around US$8billion. While still in the early stages of development and costly in comparison to conventional vehicle propulsion and fuel technologies, fuel cells and hydrogen offer a promising solution to address growing concerns over the transport sector's dependence on oil and its impact on climate change.

The large number of hydrogen fuel cell prototype vehicles, from two-wheelers to cars and buses, already plying the roads in over a dozen countries is accelerating the learning process in the development of these technologies. The European Union, for example, is engaged in fuel cell bus trials in several cities and foresees that 20% of transport fuel will come from hydrogen by 2020. Japan has a demonstration programme with 60 vehicles and 10 refuelling stations and has plans to commercialize five million fuel cell vehicles by 2020. The United States is undertaking research and development leading to specific performance targets and a commercialization decision in 2015. Over 100 vehicles and 17 fuelling stations are being tested in the state of California alone.

The high cost of these demonstration projects, however, has limited the participation of developing countries in this learning process. Currently only three of the five developing countries initially involved in the Hydrogen Fuel Cell Bus demonstration project—Brazil, China and India—have set up demonstration projects in major urban centres. Although the programme is partially underwritten by the Global Environment Facility (GEF), Egypt and Mexico are seeking less costly alternatives to reduce pollution in their capital cities. Most developing countries remain unaware of the progress being made in the development of fuel cell technologies.

A number of manufacturers, for example, are exploring niche markets among potential early adopters of HFC powered vehicles such as forklifts for warehouses, baggage handling equipment at airports and golf carts. But the speed with which hydrogen fuel cell vehicles (HFCVs) mature into commercially feasible buses and cars and the necessary refuelling infrastructure is in place, remains a matter of debate. Some argue that the first of these vehicles maybe available as early as 2015, others push that date closer to 2020. But it is generally believed that we cannot expect hydrogen-fuelled cars and buses to account for a third or more of the vehicles worldwide much before 2040–2050. What should be done in the interim?

Standard setting and a variety of technological alternatives to hydrogen and fuel cells—the use of biofuels and the production of hydrogen through natural gas reforming for example—are being discussed in forums such as the International Partnership for a Hydrogen Economy, IPHE (www.iphe.net), the International Energy Agency, IEA (www.iea.org), and the Renewable Energy Policy Network for the 21st Century, REN-21 (www.ren21.net). Organizations such as IPHE and the IEA, however, have few members from the developing world (only Brazil, China and India), while REN-21 has adopted a focus on alternatives that does not include hydrogen and fuel cells. Does this mean that developing countries should simply 'wait and see' what develops in the North with regard to the latter? Participants at the Maastricht Conference on Hydrogen Fuel Cells and Alternatives in the Transport Sector would not agree. How then might developing countries approach technological choices strategically and begin to plan for a potential shift to hydrogen and fuel cells?

Dealing with technological exclusion

Hydrogen and fuel cells are 'new wave technologies' in the sense that they differ from earlier industrial technologies in the importance of their science base, the role of patenting and their systems embeddedness. If we look back to the introduction of previous new wave technologies such as Information and Communications Technology or biotechnology, the current situation for developing countries in dealing with the emerging fuel cell and hydrogen technologies is particularly challenging. Most developing countries were unprepared to deal with these technologies, giving rise to 'technological divides' and 'knowledge and infrastructure gaps' that have lasted for decades. To avoid the problem of exclusion this time around, setting priorities and making choices are needed now.

In a few of the developing countries, notably Brazil, China and India, research on hydrogen fuel cells for both stationery energy and transport is already underway. In China, where the focus is primarily on the development and Commercialization of fuel cells for the transport sector, the Ministry of Science and Technology (www.most.gov.cn) approved a budget of 880 million Yuan/ USD 106 million for its 10th five-year plan (2001–2005), the bulk of which will be spent on the commercialization of fuel cells in the transport sector. Most of these funds support research and development activities undertaken through consortia involving public sector research institutes, universities and companies in the Shanghai, Beijing and Dalian areas.

> Fuel cells and hydrogen offer a promising solution for the transport sector's dependence on oil and its impact on climate change

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In India, where the Hydrogen Energy Development Board is under the Ministry of Non-Conventional Energy Sources, attention is paid to a broad range of alternatives that range from the development of proton exchange membrane fuel cells (PEMFCs) for two, three and four wheeled vehicles, to the application of compressed natural gas (CNG) in the transport sector and the development of bio-fuels such as diesel extracted from local non-edible oilseeds. Many of India's largest companies in the energy sector are collaborating with local universities and research institutes in the development of PEMFCs. In Brazil, much of the research and development related to electric vehicles and hydrogen fuel cell technologies is carried out with the support of Petrobras, the national oil company, CENPES, its affiliate in Rio de Janeiro and LACTEC, the technological development institute in Curitiba. Alternative fuels such as ethanol and more recently, biodiesel, are also a focus of attention. China, Brazil, India, Malaysia and South Africa have also engaged in domestic consultative processes to prepare hydrogen road maps that set priorities and establish targets.

As the above examples illustrate, there are a number of key activities that could help to deal with the problem of technological exclusion in other developing countries. These lay the basis for policy readiness and open channels for the flow of knowledge and information that makes possible informed decision-making on these issues. One activity is to create public awareness of hydrogen fuel cell technologies and their alternatives. Without a solid knowledge base, translating this awareness into policies and programmes of relevance to local conditions and needs would be difficult.

A second activity, therefore, is to strengthen tertiary education and pubic sector research as a means to build the capabilities needed to evaluate these alternatives and thus open opportunities for earlier adoption than has been the case in the past.

Creating a knowledge base, however, is costly. Regional research and development nodes that are already emerging in countries such as Brazil, China and India could become the nodes in a network of centres of excellence for training and research in the South. This would spread the costs and speed up the process of mastering the new technology. Local research and consultative processes are also essential in setting priorities and making informed policy choices in new wave technologies. So, too, is the need to monitor the advancing frontier in hydrogen and fuel cell R&D, the speed with which these technologies are being applied and the social, economic and environmental impacts. Networking across the South and the establishment of North-South partnerships provide valuable opportunities for learning and reduce the costs of doing so.

Learning about alternatives

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. While 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. 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

Fuel Cells Explained

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.

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 biofuels 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.

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.

Lessons from programmes in the South

The developing world has already experimented quite significantly with alternatives in transport technology. To reduce levels of urban pollution, cities such as Curitiba in Brazil, Bogota in Colombia, Mexico City, and New Delhi in India for example, have built bus corridors and/or introduced incentives for buses and taxis to use alternative fuels. Some of the largest natural gas vehicle programmes are in Asia and Latin America. Argentina and Brazil have upwards of one million natural gas vehicles each (Table 2). Mexico, China, Iran and Thailand have significant liquefied petroleum gas (LPG) fleets.

Brazil, which has long boasted the world's largest biofuel programme based on ethanol produced from sugar cane, has recently introduced flexfuel cars that run on any mixture of gasoline and ethanol. In 2004, 26% of all new cars were flexfuel. Many countries, including India and China, have begun blending ethanol with gasoline and several countries have taken a growing interest in biofuel production from crops like jetropha, coconut oil, and palm oil, including several African countries.

1. Access to energy resources 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 biofuel 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.

2. 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.

3. New fuel markets build on existing capacities

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 programme

Without a solid knowledge base, it is difficult to translate awareness into policies and programmes relevant to local conditions and needs

Table 1. Possible Fuel/Propulsion System Combinations

	Spark Ignition	Compression Ignition	Fuel Cell	Reformer + Fuel Cell	Electric Motor
Gasoline	*		*		
Diesel		*		*	
CNG	*			*	
LPG	*				
Hydrogen	*		*		
Methanol	*	*	*	*	
Ethanol	*	*		*	
Biodiesel		*			
DME		*		*	
Electricity					*
F-T		*		*	

Source: Frost and Sullivan, *Fuels for Road Transport*: Final Report. Prepared for Workstream 3 of the SMP, December 2002. Unpublished as cited in World Business Council for Sustainable Development (WBCSD), *Mobility 2030: Meeting the Challenges to Sustainability*, 2004.

is 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.

4. 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 fleets 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.

Table 2. Top Natural Gas Programmes in Developing Countries

Country/ Programme	Vehicles	Refueling Stations
Argentina (2005)	1,413,664	1,342
Brazil (2005)	1,000,000	1,342
Pakistan (2005)	600,000	670
India (2004)	204,000	198
China (2003)	69,300	270
Egypt (2004)	52,000	79
Venezuela (2004)	50,000	140
Colombia (2004)	43,380	78
Bangladesh (2004)	31,988	79
Iran (2004)	22,058	40
Bolivia (2005)	28,790	59
Malaysia (2004)	12,000	38
Chile (2005)	5500	13
Thailand (2005)	4,905	31

Source: IANGV, *Natural Gas Vehicle Statistics*.
Available at: http://www.iangv.org/index.php?CategoryID=37

Hydrogen Road Maps for Developing Countries

Across the South, needs are different and a standardized approach to transitions in energy and transport would not be appropriate. A number of developing countries are thus creating energy strategies and hydrogen road maps that evaluate their own options, set priorities and establish targets and timetables. South Africa, for example, assigns a central role to its exports of platinum, which is a key component of fuel cells, and to the use of fuel cells for rural stationary power as a means of bringing about greater social and economic inclusion. Malaysia, which will be a net importer of oil and gas in 15 to twenty years' time, is focused on energy security and

Hydrogen road maps help create public awareness and consensus on potential pathways to hydrogen in different countries

is presently in the process of developing a roadmap for the expansion of solar energy, the introduction of renewable hydrogen energy and the application of fuel cells as the primary energy conversion devices for the latter.

Hydrogen road-mapping exercises in developing countries are thus raising the profile of hydrogen fuel cells for stationary power in off-grid and rural areas alongside other off-grid generation methods such as improved biomass, solar and wind. Hydrogen road maps have also been useful devices in creating public awareness and consensus on potential pathways to hydrogen in different countries.

From a medium and long term development perspective, the emergence of a new wave technology, by definition, has implications for a wide spectrum of other industries in a country's economy. In thinking about transitions, it will also be necessary to take these sectors into consideration.

For oil producers in the South, for example, should the EU and the US meet their current targets for alternative energies and China joins India and Brazil in taking a strong position on the need to promote alternative energy technologies, there is likely to be a significant drop in oil consumption and revenues, potentially within 20 years.

A quick look at oil consumption in the United States, where the transport sector depends on petroleum for 95 percent of its fuel and transport accounts for 67 percent of US petroleum use, would support such a dramatic drop in oil consumption if HFCVs and alternatives based on bio-fuels and carbon neutral electric power were to reach one third of all vehicles on the road globally by 2030. While this allows for a period of time in which to develop alternative uses for fossil fuels, such alternatives will have to be identified and the research and production capabilities put in place over the next 10 to 15 years. Yet only a few oil producers have begun to move strategically in this direction.

Similarly, for developing countries that have become involved in assembling automobiles and producing parts and components, the cars of the future will require new skills and new knowledge.

Strengthening the local knowledge base, ensuring its flexibility, engaging more intensively in domestic demand-driven research and creating new sorts of knowledge networks and partnerships will be needed to make the transition in this industry less painful. Little thinking about a transition has, as yet, been undertaken by developing country auto and auto-parts producers.

More broadly still, developing countries run the risk of moving down an older technological path as they continue to build their vehicle-related infrastructure—the auto repair services, fuel distribution networks, fuelling stations—around the internal combustion engine and the consumption of oil, without also investing in alternatives. This is all the more serious as many developing countries have become major importers of used cars and trucks, thus creating a stronger incentive to strengthen a fossil fuel-based system. Were this to continue, North and South would find themselves on divergent paths with an ever wider technological divide between them.

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