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Methanol infrastructure — will it affect the introduction of SPFC vehicles?

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Abstract

The possibility that future solid polymer fuel cell vehicles will be fuelled by methanol has been suggested. If this is the case, it will have significant implications for the future structure of the methanol supply industry, and methanol supply and availability may have an impact on the take-up of these SPFC vehicles. In this study, a model assessing the possible future penetration of methanol SPFC vehicles was constructed. This suggested that it would be possible for SPFC vehicles to achieve rapid market penetration after an initially slow start. A further model indicated that methanol supply would be adequate for vehicle demand until about 2013, when significant new capacity would be required. The cost of this new capacity was estimated, along with the cost of providing refuelling infrastructure such as road tankers, storage, and suitable fuelling stations. Amortising the cost over a short period (to 2013) could double the pre-tax price of methanol as a fuel, while over a longer timeframe (to 2029) it would add less than 10% to this value. The model suggests that methanol capacity need not be a constraint to the future introduction of SPFC vehicles using it as a fuel, but that other factors such as fuel purity and safety must be carefully considered before real costs can be calculated. © 2000 Elsevier Science S.A. All rights reserved.

Keywords: SPFC; Fuel cell; Methanol supply; Fuel infrastructure; Fuel cost

1. Introduction

It is becoming increasingly clear that the fuel cell is being considered as the possible successor to the internal combustion engine by the automobile manufacturers responsible for the majority of world production. DaimlerChrysler, Ford, General Motors, Toyota, Nissan and Honda are all committed to the introduction of fuel cell vehicles in the period 2003-4.

However, it has not yet been resolved what fuel these vehicles will require. Ideally, the solid polymer fuel cell (SPFC) that will be used in these vehicles would operate on hydrogen directly, but it has been suggested that the infrastructure and on-board storage issues associated with pure hydrogen need some time to be resolved. Alternative fuels include other hydrogen-rich hydrocarbons — principally synthetic diesel fuels — and methanol, each of which requires fuel processing equipment on board the vehicle, making the system more complex and adding to the cost.

At one point it seemed likely that all of the car manufacturers would adopt methanol as a compromise fuel — easier to reform on board than fuels with multiple carbon bonds such as synthetic hydrocarbons, yet simpler to transport than pure compressed or liquid hydrogen. While a final decision has yet to be taken, it is clear that methanol, in widespread use as a fuel would require a production and distribution infrastructure that may be very different from that presently in place for its use as a commodity chemical. The prospective infrastructure requirements and how they might affect the introduction of SPFC vehicles are now investigated. This work was performed under contract to ETSU as part of the UK Department of Trade and Industry's Advanced Fuel Cells Programme. A report detailing that study and its conclusions is available [1], covering additional items such as alternative sources of methanol production and their impact on, for example, CO_2 emissions.

2. Present methanol production and supply

In order to set the scene, it is useful to understand the present situation with regard to methanol supply world-

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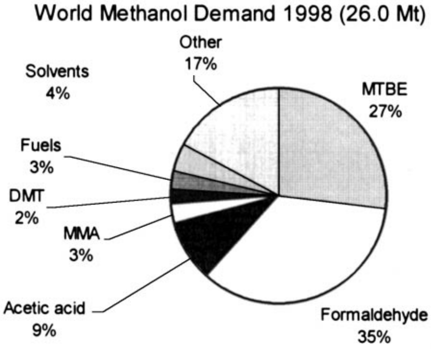

Fig. 1. World methanol demand by end-use.

wide, as any future fuel infrastructure will be based on a worldwide supply chain. In 1998, worldwide demand for methanol was in the region of 26.0 Mt [2]. This was primarily made up of demand for formaldehyde, MTBE and acetic acid, with other products making up the balance as shown in Fig. 1. Demand was distributed throughout the world in the ratios given in Fig. 2.

Worldwide methanol capacity, for comparison, in 1997 was about 33.5 Mt [2,3], giving an operating rate of approximately 80%. This has been projected to continue until at least 2002 [4]. The slowdown of the Asia-Pacific markets has also hit world consumption, however, and this may remain flat for 1998 and 1999 at least — not rising as in previous forecasts. In addition, the Californian administration has decided to phase out MTBE as an additive to fuel by 2002, possibly with tremendous impact on future methanol markets. Since considerable new capacity has already been committed in Saudi Arabia, Chile, Trinidad and other areas [5], the slack in the market is likely to rise above 20% (about 7 Mt). Unless some consolidation occurs, with more expensive production shut down, or new markets are found, price uncertainties within the methanol market will continue for some years.

3. Methanol for fuel cell vehicles

Methanol can be used in fuel cell vehicles, either with an on-board reformer or in the future, using a direct methanol fuel cell. In order to enable the introduction of these vehicles it will be necessary to provide a methanol fuelling infrastructure. The extent of this will be driven, in turn, by the numbers of fuel cell vehicles in the market.

In order to understand some of the drivers and constraints of possible future fuel cell vehicle fuel requirements, it was necessary to construct a model of SPFC vehicle uptake in the medium term (to 2030). A number of constraints were adopted, such as the consideration only of passenger cars and light goods vehicles (LGVs), and the development of a model that addressed only part of the world - North America, Western Europe and Japan. These were felt to be the most likely early markets for fuel cell vehicles.

The model itself, shown schematically in Fig. 3, was a combination of two models: a general model of the total vehicle stock, following the one used in Energy Paper 65 [6], and a model of the growth of the share of SPFC vehicle stock within the market for all vehicles. Road that is car and LGV, methanol consumption is the product of the SPFC vehicle stock (V) multiplied by average car use (U) multiplied by the average SPFC vehicle fuel economy (E). That is,

$$M = VUE$$

SPFC vehicle stock is calculated from the total vehicle stock in the country multiplied by the share of new vehicle sales that are SPFC vehicles, taking into account vehicle scrapping and replacement, approximately every eight years.The total vehicle stock is a function of:

- income, for cars, and GDP, for light goods vehicles,
- real price of a traditional car,
- real price of the weighted average fuel
- and road congestion.

The model uses different parameters for each geographical region under consideration, and a picture of overall SPFC vehicle penetration is developed by combining the results from these separate modelling exercises. Three scenarios are investigated: ‘slow’, ‘reasonable’ and ‘rapid’ growth, in order to test the sensitivity of the outcome to the input parameters. The key variables are given below in Tables 1–3. In all scenarios, the relative price of conventional and fuel cell vehicles has been kept equal. This was considered to be justifiable in that although the fuel cell technology will require significant investment and volume manufacture to bring down costs to levels that are competitive, the first vehicles are likely to be subsidised by the

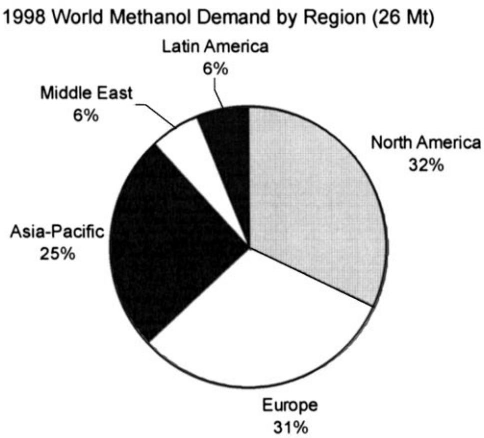

Fig. 2. World methanol demand by region.

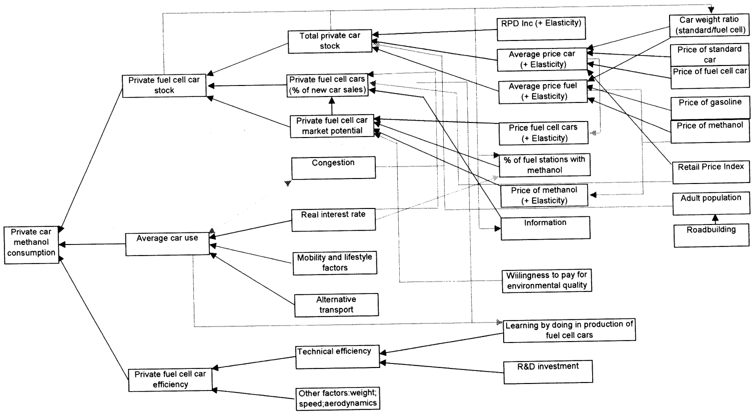

Fig. 3. Model used for estimating growth in SPFC vehicle stock.

manufacturers in the same way as the Toyota Prius hybrid vehicle.

4. Prospective fuel cell vehicle penetration

The model produced the outcomes shown in Fig. 4 for possible SPFC vehicle introductions in the areas considered. It is important to consider that actual penetration is likely to be substantially different in many ways, not least because the model assumption relates specifically to methanol fuel cell vehicles that are in direct competition with gasoline internal combustion engine vehicles — no other alternatives are considered. This is felt to be justifiable in that the aim of the study is to understand the *limiting* effects of methanol provision on SPFC vehicle growth, so that the most positive scenario can be considered.

It can be seen that from the base date of 2003, when vehicles are assumed to become available, growth is slow until 2013, when it rapidly ramps up. Vehicle sales are of the order of 10 m vehicles in 2013, 40 m in 2016 and 50 m in 2019. This sudden change to rapid growth is partly an effect of the replacement cycle of vehicle stock, which takes about eight years on average, and is partly dependent on the availability of methanol refuelling stations. It is important also to note that the difference between the three scenarios is not that great, lending some legitimacy to the 'rapid' and 'slow' margins of the analysis.

Table 1
Assumptions for 'slow growth' scenario

Assumptions	Slow growth		
	N. America	Europe	Japan
Relative price (SPFC/ICE)	1.00	1.00	1.00
Relative price (methanol/gasoline)	1.00	1.00	1.00
Interest rates	3%	3%	3%
WTP for environmental quality	2%	2%	2%
Fuelling stations with methanol (growth)	1%	1%	1%

WTP: willingness to pay — assumed to be a small number of people who will buy alternative fuel vehicles even if they are not economically competitive.

5. Implications for methanol supply

The crucial element of the study is the effect that this projected increase in demand for methanol vehicles will have on methanol as a fuel and thus on methanol supply. Allowing for projected efficiencies of fuel cell vehicles and taking average figures for annual vehicle mileage enables the calculation of future methanol demand, shown in Fig. 5 for the 'reasonable' scenario.

The world business as usual (BAU) scenario indicates the level at which conventional methanol demand is expected to rise (chemical uses). Supply capacity would probably follow the historical trend and remain 10–20% higher than the BAU demand. It is clear that only after the consumption spiral begins in 2013 does projected capacity for methanol production become a possible significant limiting factor in the case of world consumption, and that, up to that point, the world SPFC vehicle fleet can be supplied without the need for additional methanol production capacity. Once the watershed is reached in 2013, however, new capacity is required and must be added at a considerable rate.

In order to understand the influence this tremendous increase in demand over conventional projections would

Table 2
Assumptions for 'reasonable growth' scenario

Assumptions	Reasonable growth		
	N. America	Europe	Japan
Relative price (SPFC/ICE)	1.00	1.00	1.00
Relative price (methanol/gasoline)	1.00	0.80	0.90
Interest rates	3%	3%	3%
WTP for environmental quality	5%	5%	2%
Fuelling stations with methanol (growth)	3%	3%	3%

Table 3
Assumptions for 'rapid growth' scenario

Assumptions	Rapid growth		
	N. America	Europe	Japan
Relative price (SPFC/ICE)	1.00	1.00	1.00
Relative price (methanol/gasoline)	0.70	0.70	0.70
Interest rates	3%	3%	3%
WTP for environmental quality	10%	5%	5%
Fuelling stations with methanol (growth)	3.5%	3.5%	3.5%

have on the supply infrastructure, it is necessary to model the growth in infrastructure required over time.

6. Infrastructure model

The infrastructure model was devised as a considerably simpler tool than the demand model, being driven almost exclusively by the demand for methanol rather than the complex series of factors affecting SPFC vehicle demand. No attempt was made to second-guess where in the world additional capacity might be added. The long timescale and the availability of a variety of alternative raw materials for methanol production will enable methanol producers to determine capacity addition when it becomes appropriate, though associated gas fields, where flaring has become a sensitive issue, may offer early solutions.

The infrastructure model makes an estimate of the number of filling stations required to service the number of vehicles predicted in the initial demand model, and also of additional road tanker and bunker storage to enable efficient supply of methanol to these stations. It is assumed that any extra shipping construction will be undertaken by the methanol producers and suppliers, and will simply be funded in the same way as at present, as part of the total cost of methanol to the consumer.

Equally, additional methanol capacity is assumed to be installed by the producers. While the model makes estimates of how many world-scale plants will be required at a given time, and of the approximate capital cost, it makes no attempt to identify who might build these or what raw material will be used to produce the methanol.

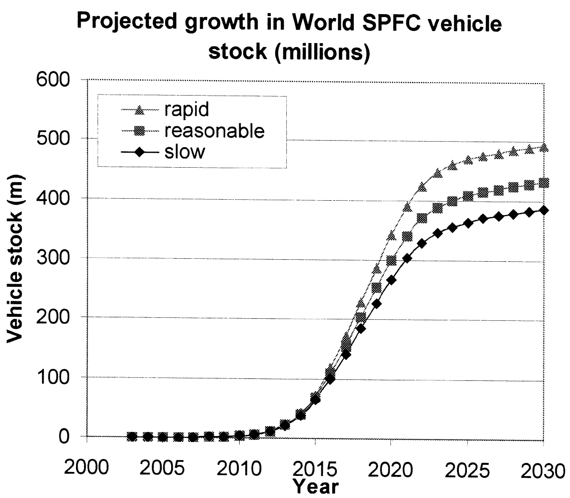

Fig. 4. Potential growth in world SPFC vehicle stock.

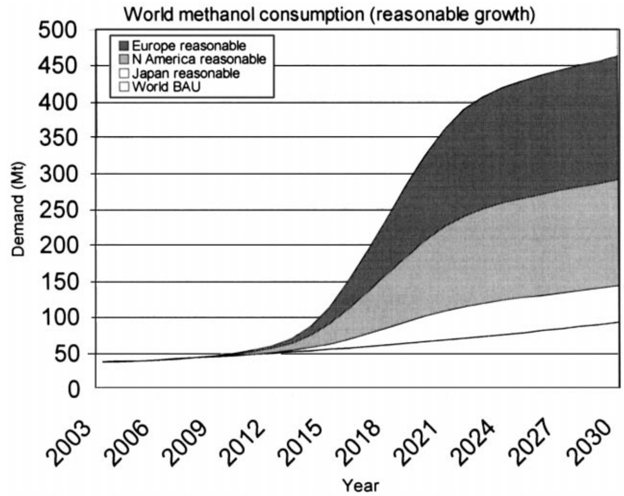

Fig. 5. Geographical composition of world methanol consumption (reasonable growth).

Assumptions regarding the distribution infrastructure required have been taken from Refs. [7,8], and these are listed in Table 4. It appears from these sources that storage, distribution tankers and filling station conversion will be all that is required. Bunker storage is assumed to increase approximately in line with methanol demand. In practice, this is a conservative assumption, as better management techniques should enable the use of minimal storage facilities, in the same way as the present gasoline distribution chain.

Requirements for additional filling stations and other infrastructure elements were first calculated in terms of numbers and then translated into cost projections. These are shown in Fig. 6. The capacity investment shown represents only plant build and not distribution infrastructure, which is indicated by the yearly spend curves. These denote the annual expenditure for replacement of

Table 4
Key infrastructure assumptions

Basic model assumptions	
Factor	Assumption
Capacity cost	£220/t
Reduction for large installations	−25%
Methanol price: 8 p/l + Distribution: 6 p/l	14 p/l
Gasoline — untaxed	15 p/l
Filling station conversion	£30,000[a]
Distribution efficiency	97%
Tanker cost	£125,000
Storage tank	£5/t

[a] £30,000 is considered a reasonable assumption for a single tank at a filling station. Local legislation could affect this considerably.

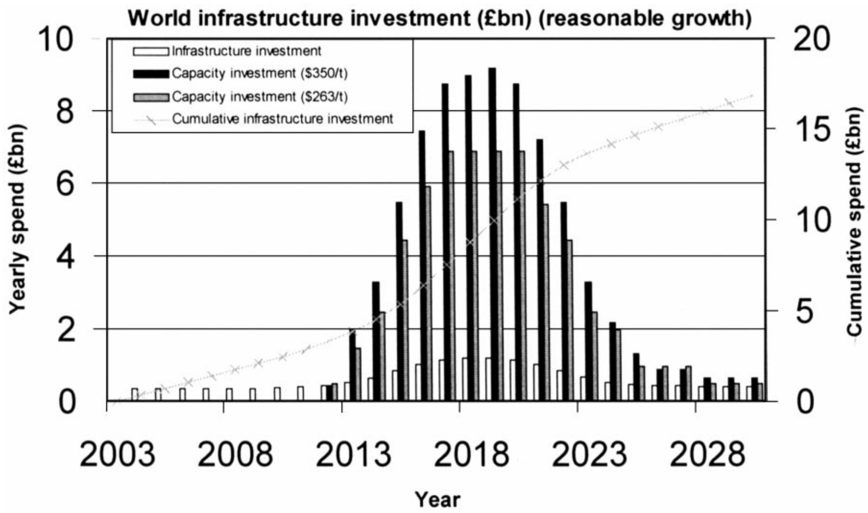

Fig. 6. Estimated requirement for infrastructure and capacity investment (World).

tanks plus associated equipment with new ones at US$50,000/unit [8]. The cumulative total expenditure is then tracked on the secondary axis. Infrastructure within a country is assumed to comprise additional bunker storage, tanker fleets and filling station conversion, with costs taken from an analysis by [7]. These are detailed in Table 4.

Capacity investment is a very significant figure that has not been included in the cash flow analysis. It was felt that additional plant build was a natural response to market pressures, and would be undertaken as part of the conventional modus operandi of a company, and internalised, as at present, through methanol sales. Although it is clear that the amount involved will be very large, peaking at US$9 bn according to Fig. 6 and that N. America may be an inappropriate location to install new plant, even in the present low market capacity is under construction in, for example, Trinidad and Saudi Arabia.

In order to add some perspective to the analysis, the additional transmission and distribution infrastructure cost has been calculated in comparison with the existing world price of methanol, and is shown in Table 5. The calculation was carried out using discounted cash flow analysis techniques, with discount rates of 10% and 15% to represent different company perspectives. The time frame was also varied, with short and medium-term return on investment considered. This has a significant impact on the additional cost of methanol.

Table 5
Additional cost of infrastructure to be included in methanol price

Additional cost of infrastructure (¢/l)		
	World	
Discount rate	10%	15%
to 2013	15.8	18.7
to 2029	1.0	1.4

As is clear from the table, over the full timescale to 2030 (or 2029, as the infrastructure is already assumed to be in place one year in advance), the additional cost of methanol is small — less than 10% of the present methanol price of 13¢/l. If, however, the cost is amortised over the first 15 years to 2013, it is heavily skewed due to the immediate need for more tankers, for example, to transport the methanol locally. In this case the cost may even double.

7. Other considerations

This analysis has focused specifically and deliberately on selected aspects of the methanol supply chain and infrastructure that may influence the uptake of SPFC vehicles *if they are methanol fuelled*. The aim of the study was to ascertain whether methanol supply would be a constraint in the short term, or if requirements for fuel cell vehicles would prove problematic for a methanol infrastructure in the longer term. There are many other factors that must be considered before a methanol infrastructure can be put into place. Amongst them are health and safety, standardisation, fuel purity for fuel cell vehicles, availability of alternatives such as hydrogen, and public acceptance. In addition, somebody must be prepared to invest in an infrastructure. Some of these factors have been considered in more detail elsewhere (e.g., Refs. [1,9,10]); others require further thought.

8. Conclusions

The modelling has shown that in principle, it is possible for future SPFC vehicles to be supplied with methanol from existing capacity up to about 2013, even considering aggressive penetration scenarios. After this point, it becomes necessary to add methanol manufacturing capacity at a high rate to keep pace with demand. Nevertheless, the cost of this addition need not be prohibitive to the uptake of these vehicles. Additional infrastructure could be financed in the long run by adding less than 0.5% to the untaxed price of a litre of methanol; in the short-term this figure could be significantly higher.

The study does *not* attempt to ascertain the best fuel for SPFC vehicles, nor the fuel that is most likely to be used.

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