The Economic Argument for Hydrogen

2010 will likely be the first year of mass produced fuel cell based products.

The implied cost of the necessary Hydrogen infrastructure drops to $2,000 to $9,000 billion down from the $4,000 to $20,000 billion range - once the figures are adjusted for the fact that fuel cells use the energy liberated 2 to 3 times more effectively that any hydrocarbon based system.

This greater efficiency of fuel cells is overlooked – their widespread use would more than halve the world's total primary energy requirement from 9,405 million tonnes of oil equivalent per annum to only around 4,297 million tonnes.

This would "save" around $1,048 billion each year that would have been spent on oil.

(The International Energy Agency estimates that an incremental $10,000 billion will be required over the next 30 years to cover only the expansion and replacement of parts of the World's energy sector infrastructure. Even allowing for the forecast 60% increase in the World's total primary energy requirement the entire cost, not just the incremental expense, of switching to hydrogen would by then only amount to $14,500 billion. By then the annual "saving" would increased to $1,525 billion each year that would have otherwise been spent on oil and could finance the switch within 10 years.)

Under our current assumptions the initial market opportunities will be in the Hydrogen infrastructure markets – worth probably between $2 and $9 trillion in total. To build out this infrastructure would equate to a 25 year growth rate of around 140%, the corresponding 50 year rate being almost 60%.

It could be paid for by the "savings" on oil expenditures within 2 to 9 years

Assuming a 20 year replacement cycle on this infrastructure would give an annual market worth between $ 90 to $450 billion, corresponding to 25 and 50 year growth rates of around 100% and 45% respectively.

The total fuel cell based product markets plus the retail value of the electricity generated globally would be worth around U$ 161 billion annually, corresponding to 25 and 50 year growth rates of almost 110% and 45% respectively.

The comparative statistics for the US, assuming that it comprises roughly 1/3rd the global total would imply an infrastructure capital investment of between $675 billion and $2,000 billion. If this was spread over 20 years it would involve an annual expenditure of only between $40 to $100 billion.

THIS IS CHEAP compared to the cost of the current Gulf War, around $200 billion, and the required repairs to the US electricity grid, another $50 to $100 billion.

There is little to choose between the cost of locally or centrally generated Hydrogen, $15 and $17 per GigaJoule.

When adjusted for fuel cells greater efficiency Hydrogen's effective/adjusted net MegaJoules/$ (MJ/$) comes in WAY ABOVE GASOLINE AND THE INTERNAL COMBUSTION ENGINE, 70 to 150 MJ/$ compared to 16 to 26 MJ/$.

Fuel cell efficiency runs at around 3x that of the Internal Combustion Engine and about 2x that of a typical gas turbine powered electricity generating station. Current Hydrogen production could power 14% of the world's present vehicle fleet but after adjusting for fuel cells' greater efficiency this figure would rise to 42%.

An Argument for Hydrogen In Detail

The issues addressed in this paper are :-

1. the probable timescale and the sequence events involved.

2. the capital investment so Hydrogen can become the world's primary energy source.

3. the impact upon the amount of primary energy consumed worldwide.

4. the size of the potential end user markets – and their implied growth rates.

5. the financial viability of locally rather than centrally generated Hydrogen – fuel cells' relative efficiency compared to current engine technology.

Methodology

The approaches used in addressing the above issues were as follows :-

Issue 1 was analysed on the basis upon widespread industry and commercial timescales.

Issue 2's examination went back to first principles and took as the starting point BP's top down annual global energy review - then all the primary energy figures in million tonnes of oil equivalent for oil, gas, coal, nuclear and hydro as well as the amounts transported by ship, and pipeline were converted into a standard energy measure (GigaJoules) - next the equivalent tonnage of Hydrogen was calculated for each category – lastly, the required capital investment was derived by using the appropriate capital costs per tonne of Hydrogen produced, stored and transported.

Issue 3 adjusted the numerical quantities identified in Issue 2, which refer to the current Hydrocarbon based world ("old" economy), to take into account the fuel cells' greater efficiency and thereby arrive at the energy and capital investment requirements of a Hydrogen based world ("new" economy) - fuel cell installations, when compared to gas turbine and the internal combustion engine based facilities, require respectively 1/2 and 1/3 the amount of energy to deliver the required solution.

Issue 4 assumed that the entire conversion would take place over a period of 25 or 50 years and then worked back from the forecast market sizes to derive growth rates.

Issue 5 compared microeconomic figures obtained for the various alternative fuel choices, the relevant power generation devices and their degree of efficiency in using that power to determine whether the use of hydrogen as a fuel and its local production are economically viable.

Summary

1. 2010 is a realistic date for the mass production of fuel cell related products to be underway – on the basis of the table below this fits in with companies' current field testing of products and the "normal" pattern of manufactured product research, design, build and mass production – fuel cell assembly is more akin to light manufacturing/assembly so that a plant would take 2 years to construct rather than the 3 to 4 years required for a traditional engine or component facility – "slippage" in the timetable is most likely to occur at this point or at the field test stage, when the product may have to be redesigned/retested because of component failures.

Probable schedule to mass production of fuel cell based products					
Timespan	2 Years	2 Years	2 Years	1 Year	1 Year
Years	2003 to 2004	2005 to 2006	2007 to 2008	2009	2010
Tasks	- field test prototypes - fine tune for mass output	- lock in final design - raise funds - order factory equipment	- build and equip factory - train staff - put in place suppliers	- production line fine tuned - logistics in place/tested - low volume trial output	- ramp up plant to full capacity - full mass manufacture

2. All figures from BP's annual review – the World's primary energy consumption would fall by 5,108 million tonnes of oil equivalent – assuming 7.33 barrels to each tonne and each barrel costs $28 implies the world could "save" just over $1 trillion annually that would normally have been spent upon other primary energy sources.

2002		ADJUST for FC efficiency			ADJUSTED
Primary Energy Source	Million tones oil equivalent	Assumed major use	Rival	% efficiency vs fuel cell	Million tones oil equivalent
TOTAL	9,405				4,297
Oil of which:	3,523				1,355
Gasoline	1,127	Transport	ICE	33	372
Middle distillates	1,261	Transport	ICE	33	416
Fuel oil	422	Heat/Electricity	Gas Turbine	50	211
Others	713	Heat/Electricity	Gas Turbine	50	357
Natural Gas	2,282	Heat/Electricity	Gas Turbine	50	1,141
Coal	2,398	Heat/Electricity	Gas Turbine	50	1,199
Nuclear Energy	611	Heat/Electricity	Gas Turbine	50	305
Hydro-Electric	592	Heat/Electricity	Gas Turbine	50	296

3. All figures are in US $ billions & rounded – assumes total global economy converted using 2002 figures & roughly 3 months worth of primary energy is stored – US would account for around 1/3 the current infrastructure requirement.

Worldwide total required U$ billion capex on Hydrogen infrastructure		
Hydrogen infrastructure sector	"Old Economy"	"New Economy"
Production	3,000 to 12,800	1,300 to 5,800
Storage	115 to 855	55 to 405
Transport	1200 to 6,300	550 to 3,000
Refuelling Facilities	15 to 25	15 to 25
TOTAL	4,330 to 19,980	1,920 to 9,230
Annual market – 20 year life	200 to 1,000	90 to 450

By way of comparison - US GDP is annually worth around US $12,000 bn - the Gulf War's cost is US $200 bn (and still rising) – around $50bn to $100bn has to be spent on "mending" the US power distribution grid to prevent a recurrence of the North East's recent blackout.

4. Assumes that each of the above sectors current output is zero – ignores current Hydrogen production capacity – also assumes that the time period for total conversion of the world to Hydrogen takes either 25 or 50 years – based upon BP's 2002 energy figures – the product categories use figures from previous research work carried and assumes that the relevant fuel cell based products would achieve 100% penetration.

Potential percentage growth rates – Infrastructure & Product Markets								
Sector	"Old Economy"				"New Economy"			
	25 yr % growth		50 yr % growth		25 yr % growth		50 yr % growth	
	low	High	low	High	low	high	Low	high
Production	139.38	153.68	131.50	145.77	54.72	59.27	52.15	56.77
Storage	110.10	127.66	103.99	120.95	44.95	50.88	42.83	48.64
Transport	130.76	146.59	122.82	139.38	51.91	57.03	49.56	54.72
Refuelling	93.66	97.66	93.66	97.66	39.16	40.59	39.16	40.59
TOTAL	142.92	158.24	134.89	150.38	55.86	60.70	53.34	58.24
Fuel Cells by Product	Annual Market $ billion		25 year % growth rates			50 year % growth rates		
Vehicles	35.0		100.34			41.54		
Buildings	18.5		95.29			39.75		
Portable devices	7.4		88.26			37.21		
Electricity	100.0		108.93			44.54		
TOTAL	161.4		112.94			45.93		

5. The figures used here were derived from various sources - the mid or average of what was usually quite a broad range was selected and the statistical outliers were ignored – the energy unit used was a GigaJoule (GJ) and the cost expressed in U$ - some figures were than adjusted for fuel cells' greater efficiency in using that energy – little effective difference in cost of locally compared to centrally generated/stored/distributed Hydrogen – all about $15 to $22.

Central	($/GJ)	Central vs Local Hydrogen generation/use		
Production	10	1 Gallon of gasoline works	out at $9.5/GJ	
Storage	5			
Distribution		Distance	Km	Form
Truck	2	short/medium	16 to 400	Liquid H2
Rail	2	medium/long	900 to 1900	Liquid H2
Pipeline	4	medium/long	160 to 1600	Liquid H2
Net to Refuel Station via		Form		
Truck	17	Liquid H2		
Rail	17	Liquid H2		
Pipeline	19	Liquid H2		
Local				
On-Site Reforming		Adjust for efficiency of use		
Conventional	15	15		
Fuel cell	25	12.5	Fuel cell 3X more efficient	
Electrolysis	35	17.5	than Internal Combustion Engine	
Vehicles		Adjust for efficiency of use		
Fuel Cell	17	6	Fuel cell 3X more efficient	
Conventional	11	11	than Internal Combustion Engine	
Domestic		Adjust for efficiency of use		
Electrolysis	45	22	Fuel cell 2X more efficient	
SMR	22	11	than power station/gas turbine	

Below is a more detailed analysis of the net amount of energy available per dollar spent on acquiring it – as an energy source hydrogen is initially more expensive than gasoline - the fuel cell's greater efficiency is key to a hydrogen/fuel cell combination being far more economic than the gasoline/internal combustion engine combination.

COMPARATIVE POWER GENERATION COSTS				
H2	MJ/$	Efficiency	net MJ/$	Comments
$5/GJ	200	75%	150	efficiency whole installation 70-80% with cogeneration
		55%	110	(50-60% without)
$8/GJ	125	75%	94	efficiency whole installation 70-80% with cogeneration
		55%	69	(50-60% without)
PETROL	MJ/$	Efficiency	net MJ/$	
$1.25/132MJ	105.6	25%	26	
		15%	16	

EFFICIENCY RANGES	Minimum	Maximum
Fuel Cell	50	60
Fuel Cell with cogeneration	70	80
Internal Combustion Engine	15	25
Gas Turbine	25	35

The following comparative statistics are for the efficiency of just the power generation device – the figures ignore such additional efficiency penalties such as transmission/rolling resistance, other frictional forces or power distribution wastage – around 12% of US electricity is "lost" across the US distribution grid.

ENGINE EFFICIENCY - before transmission/rolling resistance inefficiencies included			
Fuel	Engine	% Efficiency	Comments
H2	Fuel Cell	100%	H2 in pressured tank, gives 4x range of petrol
Methanol	Fuel Cell	80%	drops to 50% if all reforming inefficiencies included
Petrol	Internal Combustion Engine	40%	