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Lighthouses for Hydrogen

Jeremy Bentham, the head of Shell Hydrogen, aims to implement "lighthouse projects" – shining beacons in the future hydrogen economy. Setting up mini-networks of hydrogen filling stations, even before there are hydrogen cars in the showrooms, is to be such a "lighthouse". If hydrogen cannot be bought anywhere, nobody will buy a hydrogen-fuelled car.

Jeremy Bentham: "In Shell's vision, the future will be a mix of motor fuels.'

Jeremy Bentham doesn't know whether the first car his son James, now six, buys will be powered by a hydrogen fuel cell. Probably not, because when you're 18 you usually can't afford a new car. But Jeremy, who is CEO of Shell Hydrogen – Shell's business unit for hydrogen – does believe that in twelve years' time hydrogen-fuelled cars will be in the showroom and that, by then, people will be able to fill up with hydrogen on the road.

Now that we're looking into the future, let's ask about his long-term vision of the market penetration of fuel cell cars. "Between 2015 and 2025, we expect the first real market penetration of fuel cell cars, starting in the United States, Western Europe and Japan," says Jeremy. "This will quickly grow into a substantial market." More specifically: "We foresee the potential of five to ten million fuel cell cars on the road in 2020, 50 million in 2030 and 150 million in 2040. By that year, half of the new cars sold in those parts of the world will be fuel cell cars, which automatically means we accept that the other half will still be gasoline or diesel fuelled. Rumours of the impending death of the internal combustion engine will turn out to be greatly exaggerated. It will remain a key player for a long time. In Shell's vision, the future will be a mix of motor fuels."

It takes quite an effort of the imagination for an outsider to absorb figures in the millions. In 2004 there are not more than 500 fuel cell cars worldwide: a small fleet of cars belonging solely to the R&D departments of large car manufacturers, and here and there some urban buses as part of European demonstration projects like the one in Amsterdam North. From his office, Jeremy can watch the buses driving past. On cold days they emit the tell-tale plume of water vapour from the roof-mounted exhaust.

Hydrogen filling stations for public use, like the Shell station in Iceland's capital Reykjavik and the one being built on Benning Road in Washington D.C., are altogether exotic But no matter how modest the beginning, Jeremy Bentham views every new fuel cell car and every new hydrogen filling station as an important signal, a first shining light. That is why he is so keen to present new "lighthouse projects" as he calls them: "They give us a glimpse of how the future will be. People must be able to see the miracle of hydrogen technology with their own eyes. It mustn't just be something they read about."

How much does hydrogen cost?

Is hydrogen, in fact, as exotic a product as it often seems now? As is often the case, the answer depends on how one looks at it. "Most people aren't yet aware that industry already produces some 50 million metric tons of hydrogen per year," says Jeremy phlegmatically. "Hydrogen is produced at literally thousands of locations in the world, for instance at refineries and in the petrochemical industry. Shell produces more than 7,000 tons a day."

Of those 50 million tons, only 3 million tons are sold "over the fence". The rest is all used in the manufacture of products, mainly advanced automotive fuels, at the sites where it is produced. Ninety percent of the 3 million tons is literally sold "over the fence" to industrial businesses adjacent to the hydrogen production plant.

So there is a great deal of knowledge available about producing hydrogen on a large scale and transporting it over short distances, but its distribution and marketing as an automotive fuel is largely uncharted territory. The cost of producing hydrogen is also well known, at least if you're producing thousands of tons a day which are then transported through a pipeline running no further than a few hundred metres. In that case, the cost is less than one dollar per kilogram hydrogen, produced from natural gas by the steam reforming process. "But if you were to order a single load of one hundred kilograms of hydrogen, to be delivered to your doorstep, the price would be nearer fifteen dollars per kilogram," Jeremy Bentham points out.

At that price, it's difficult for hydrogen to compete with gasoline and diesel, because the energy value of one kilogram of hydrogen corresponds with that of one American gallon (3.8 litres) of gasoline. In the United States, one gallon of gasoline now costs about $2, whereas in the Netherlands the equivalent quantity costs around $6.

This too must be viewed in context. "In the future, the hydrogen retailed at a filling station will not, of course, cost $ 15 per kilo," says Jeremy. "If automotive hydrogen is produced centrally at the plants where it is produced now, the production costs will work out at less than a dollar per kilogram. As sales through filling station networks grow, the distribution costs will fall. In a mature market in terms of volume, it should be possible to make and distribute hydrogen for $2-3 per kilogram, excluding taxes, levies and excise duty."

"And hydrogen has another unique trump card when compared with gasoline," Jeremy adds. "A fuel cell car uses a completely different drive technology, which allows it to cover twice the distance on a kilogram of hydrogen that a conventional car can drive on a quantity of gasoline with the same energy value. And an electric fuel cell car gives a very comfortable ride and very fast acceleration."

Big Cake

The "chicken or the egg" problem is obvious. If hydrogen-powered cars are to become popular, (affordable) fuel cell cars must be available in the showrooms, and motorists must be able to fill up with hydrogen quickly and easily and at many different places. But if there are no fuel cell cars, there won't be any hydrogen filling stations, and without the filling stations, hydrogen cars won't be sold. If fuel cell cars are very expensive, and hydrogen costs more than gasoline, then Jeremy Bentham's vision of the miracle of hydrogen technology is

"We foresee the potential of five to ten million fuel cell cars on the road in 2020, 50 million in 2030 and possibly 150 million in 2040."

A fuel cell bus in Amsterdam – only water from the exhaust.

doomed. How can this dilemma be resolved?

Jeremy says that there are two parts to the answer. Firstly, large joint ventures must be formed: these could be public private partnerships of vehicle manufacturers, energy companies, technology developers, large fleet owners and national and international government authorities. Secondly, subsidies are required to get things off the ground.

Let's look at the two answers in greater detail. Firstly, why public-private partnerships or PPPs? "Eventually, everybody's goal should be to set up a healthy hydrogen industry," Jeremy replies. "With PPPs we can jointly ensure that the partners can achieve their own aims through synergy, and also that the cake will grow as fast and as big as possible."

He shows by calculation that the cake could become very big indeed. "A fuel cell car will use an average of 250 kilograms of hydrogen per year. If hydrogen in the European context, with an excise duty system that acts as an incentive, costs $4 to $5 per kilogram at the pump, then a million fuel cell cars on the road will be equivalent to a turnover of more than one billion dollars. The energy company taking the lead in development will be able to achieve the highest margins."

High rewards, high risks? The initial investment – the money that has to be spent up front by all partners – is just as impressive as the potential market volume. Shell Hydrogen has calculated that setting up a network of hydrogen filling stations with sufficient coverage would cost the whole industry some $20 billion for the USA and Europe, and about $6 billion for Japan.

This does not include the costs that manufacturers will have to incur to develop fuel cell cars from the current prototypes into fully commercial propositions. The bandwidth here is wider: according to Shell Hydrogen this will be between $50 billion and $200 billion worldwide, spread over a ten to twenty year period. "A lot of money," Jeremy admits, "but bear in mind that in Europe alone the market position of diesel cars has been supported to the tune of more than $10 billion a year, over a large number of years. This is mainly in the form of technology development loans and lower rates of excise duty on diesel. Quite frankly, it was an eye-opener for me when I found this out."

Social acceptance

When such large sums, risks and political ambitions are at stake, it is logical for the industry to ask the government for money and support. But at the same time, the market will have to decide which technologies and systems will win, as governments cannot do this. This is another argument for the PPP approach.

Four key issues must be dealt with by these broad-based alliances. Jeremy Bentham summarises them as follows:
Jointly set up an infrastructure of hydrogen filling stations.
Jointly achieve the mass production of fuel cell cars.
Introduce consistent international engineering and safety codes and standards.
Foster social acceptance and public understanding for the introduction of a hydrogen economy.

Including "social acceptance" in the list of key issues is not empty phraseology, Jeremy insists. "We have to make people enthusiastic about fuel cells and hydrogen, but from a realistic angle," he argues. "The prospect of a hydrogen economy can provoke divergent reactions. There's the enthusiasm of people who are fascinated by the challenge of the new, but there are also opposing forces that dread the uncertainty inevitably associated with any new technology. Many politicians are now very enthusiastic about fuel cell cars and hydrogen – to such an extent that this may even become a threat, because the expectations of the public and of consumers will be raised too high too soon. Every new technology risks being hijacked by completely opposite interest groups, in the positive and negative sense. In both cases, an unrealistic picture of the opportunities is formed, and also of the hurdles that stand in the way. This can have an impact on the market development of this new technology."

On-board storage systems

Now the word "hurdle" has been mentioned, what technological barriers haven't been overcome yet? How hard are they to overcome? "The biggest challenge is to further develop on-board good storage systems, and to achieve the mass production of affordable fuel cell systems," Jeremy explains. "But there aren't really any technological barriers that we regard as both critical and unsolvable. This is why we are so confident of the future."

Currently the "hydrogen industry complex" favours a pressurised tank in the car, integrated in the bottom of the bodywork. General Motors' new Hy-wire concept car is designed in this way. Hy stands for hydrogen, of course – and wire? All the functions of the car, including the steering, are controlled completely electronically. A fuel cell car has a huge amount of

POWER STATION ON WHEELS

Motor manufacturers are responding to the challenge of the fuel cell car concept. Ford, Toyota, General Motors, DaimlerChrysler and BMW all have concept cars on the road. Take the General Motors Hy-wire. Instead of an internal combustion engine, it has fuel cells and electric motors driving the front wheels, plus a hydrogen tank: three cylinders built into a relatively thin (28 cm) "skateboard" that forms the underside of the car's body. The tanks of the Hy-wire, made of carbon-composite material, can hold two kilograms of hydrogen stored at a pressure of 350 bar.

The car does not have any mechanical or hydraulic linkages (such as for steering or braking). Instead it has a "drive-by-wire" system, in which a computer translates the driver's commands to control the wheels, brakes, etc. Similar control systems have already been in use for some time in modern military and civil aircraft. The central computer is also built into the bottom plate of the car.

The Hy-wire gets its power from a stack of 200 fuel cells (also embedded in the bottom plate) which delivers a steady power of 94 kW with a peak output of 129 kW. The power goes to the three-phase electric motors built into the front wheels, which each deliver an impressive torque of 1,870 Nm. Breathtaking acceleration is one of the most spectacular characteristics of fuel cell/hydrogen cars.

Another special characteristic is the large amount of electricity generated onboard. For the various on-board systems, 250 and 380 volts are available.

In General Motors' vision, production of the market version of the Hy-wire could start in 2010. By then, it is expected that technological improvements could allow the fuel tanks to hold a volume of four kilograms of hydrogen, which would give a standard range of travel of 600 km.

GM already has "conventional" fuel cell cars on the road. For example in Washington D.C., where they can fill up at an existing Shell service that has been modified to supply hydrogen to this fleet of trial and demonstration vehicles.

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PIVOTAL ROLE IN PARTNERSHIPS

Shell Hydrogen is the global business unit for hydrogen of the Royal Dutch/Shell Group. The company was founded in 1999. Its headquarters are in Amsterdam, with regional offices in Houston and Tokyo.

Shell Hydrogen has two aims:
Production of hydrogen in the most economical way, and the supply of hydrogen to any market that develops for it.
Support of the development of hydrogen systems and offering the technical solutions that the world needs in order to successfully convert fossil fuels to hydrogen.
Shell Hydrogen does this mainly in the form of partnerships. As a participant in joint ventures, the company plays a role in the development of storage systems (on board cars and at filling stations), and of technologies for hydrogen purification, fuel conversion and tank storage systems.

The company is also an active partner in mobility demonstration projects in Western Europe, the United States and Japan. Hydrogen filling stations have been and are being built for these projects, for example in Tokyo, Amsterdam, Luxembourg and Washington D.C.

Thirdly, Shell is a partner in two investment funds (Chrysalix and Conduit) which provide venture capital to companies working to develop a hydrogen economy.

(More information at: http://www.shell.com/home/Framework?siteId=hydrogen-en)

electrical power available, so an extra servo motor here and there makes little difference. (See box “Power Station on Wheels”.)
Jeremy continues: “In this car, the hydrogen tank plus the electric motors and all technical systems are mounted as a kind of ‘skateboard’ beneath the car, which gives a lot of design freedom for the rest of the car. This may become the definitive direction the technology will take, or we may move on to tanks with a metal hydride core which can store hydrogen – bonded to a metal – as a powder. This is being worked on, but a breakthrough in this technology is not necessary in order to make the mass production of fuel cell cars feasible.”

Mini-Networks

All right, so the car technology will work out, especially as almost all leading manufacturers have development projects for fuel cell cars. General Motors alone has 500 people working on this.
But in view of the “chicken or the egg” problem, how can a company like Shell ensure that a network of hydrogen filling stations is developed in parallel with the expected growth in the number of customers? Shell Hydrogen believes that the only realistic approach is for energy companies, vehicle manufacturers and government authorities (providing grants-in-aid and other incentives) to create mini-networks. This would be a typical “lighthouse” project, a shining light for the consumer and society.

“Currently, hydrogen is being produced at thousands of locations in the world,” says Jeremy. “The most obvious approach would be to build mini-networks of four to six hydrogen filling stations in large conurbations like Tokyo/Yokohama, Los Angeles, New York and – closer to home – the Randstad and Rhine-Ruhr region. These retail outlets would be situated at existing filling stations, getting their hydrogen from a large-scale production plant nearby. It would be transported by road tankers and stored in pressurised tanks at the filling stations.”
And the customers? Jeremy thinks the market will be driven by innovative customers drawn by the appeal of fuel cell cars. But a start will be have to be made by “fleet companies”, the owners of fleets of, say, one hundred vehicles. In his vision, government incentives would stimulate the forming of fleets and include an arrangement to help offset the losses that hydrogen filling stations would incur during the initial phase: “Every mini-network would operate semi-commercially during this period and would be run by a public private partnership of vehicle manufacturers, energy companies, fleet owners and government authorities. Shell Hydrogen is already engaged in setting up ‘lighthouse projects’ of this kind.”

Jeremy believes that partnering is the only way to trigger the development of a hydrogen economy: “The introduction of hydrogen is not a sprint, but rather a marathon. We are running already, but we don’t mind at all if other runners want to join us. This is a typical technological and market development in which no single party can go solo. Hydrogen is good for consumers, for society as a whole, for nature and the environment, and also offers the prospect of an attractive industrial development, so it’s good for shareholders too. In the long term it will become an ordinary commercial activity with plenty of competition, but to get it up and running, there’s no alternative to working together in partnerships.”

General Motor’s Hy-wire – a prototype of hydrogen and ‘drive by wire’ technology. Ready for production maybe in 2010.