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fore front:

hydrogen: the hand-me down power?

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A clean, inexhaustible vehicle fuel that emits only water vapour – it makes great PR, but hydrogen still has to be extracted, compressed, distributed. That's going to take a lot of energy, which still has to be generated by orthodox means. Nuclear power may remain a bête noire for some environmentalists, but others now see it as the only way to make 21st century vehicles truly 'green'.

Motor transport has never been more popular, accelerating the depletion of our fossil fuels. Clean alternatives such as nuclear power are scarcely feasible for personal vehicles, so instead hopes are fixed on hydrogen gas,and particularly on its ability to release 'clean' energy from fuel cells. A certain complacency has arisen that as early as 2050, we will all be driving fuel-cell cars, and carbon monoxide emissions will have been reduced to nil. For reasons that I will go on to explain,it is not quite that simple.

In a hydrogen fuel cell, hydrogen gas combines with oxygen from the atmosphere to produce electrical energy and water vapour.The electrical energy powers the car and the water vapour is vented into the atmosphere. So a fuel-cell car emits only water vapour – no CO_2, CO or nitrous oxides.

But hydrogen is not a source of energy: like electricity it is merely a *vehicle* for storing and transporting energy. The hydrogen needed to power a fuel-cell car does not exist in nature;it is

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not a source of energy that is mined like coal, or pumped out of wells like oil and gas. It must be manufactured, and the process of making hydrogen requires energy.

On an industrial scale that energy must come from conventional power stations,fuelled by coal, oil or gas. So the emission of CO_2 is merely transferred from the tailpipe of the car to the smokestack of the power station – and the debate from the personal to the political.

Sources of industrial energy

Coal: Coal is essentially a deposit of solar energy accumulated over geological time : old plant growth, compacted and geologically processed and concentrated over the ages. We began to mine it only a few hundred years ago. There's probably enough to last a few thousand years at the present rate of exploitation.

Oil and natural gas: These fuels, like coal, are extracted from geological deposits accumulated over eons.The conventional view is that gas and oil are biogenic like coal, but perhaps older.They have been exploited for a little over 100 years; known reserves will last some few decades at the present rate of exploitation.

Solar/hydrogen power: Here photovoltaic cells convert sunlight into electrical energy, which is used in turn to produce hydrogen gas by the electrolysis of water or some other chemical process.Weingart has presented a systems analysis of a sustainable global solar energy system that even estimates its economic feasibility and environmental impact.[1] Solar energy does indeed have a place in the palette of energy sources for the future, but it seems unlikely that it will ever be able to satisfy the needs of a modern industrial economy.

Distribution

No matter how it might be produced, hydrogen has to be stored and transported to a fuel cell car. There it reacts with atmospheric oxygen, producing water vapour and the electricity to power the car. There are various systems of storage and transport, a few of which are described below.

Today we obtain energy for our cars at filling stations.We pump a tank of petrol and burn it in our car with atmospheric oxygen and dump the exhaust, CO_2, etc into the atmosphere – cheap and dirty. Suppose we fill up our fuel-cell car with hydrogen gas at a filling station.We would burn it with atmospheric oxygen in the fuel cell and release the resulting water vapour into the atmosphere. Clean, but perhaps not so cheap, as we have to create a new distribution system for the hydrogen.

Hydrogen gas might be distributed to filling stations by pipeline or in tank trucks, and transferred to a sturdy tank in the car. The technology for handling gas at high pressure and releasing it a bit at a time is well developed. It might also be distributed in the form of liquid hydrogen at very low temperature. Cryotechnology is a well developed technology – a spin-off from high-energy physics research and the space program. Some satellite-launchers are lifted off by booster rockets burning liquid hydrogen and liquid oxygen.

But some people don't like the idea of having hydrogen gas around.Aside from the mechanical problems of storing it under high pressure or at low temperature, a mixture of hydrogen with air in certain proportions is explosive (just like petrol and cooking gas). Others worry about the practicalities of creating a new distribution system for gas. So other schemes are being invented to transport hydrogen more safely and conveniently.

One such proposal consists of distributing methanol (CH3-OH) in filling stations. Methanol is a liquid and rich in hydrogen – all you need is another pump at the filling station.In this scheme methanol is 'reformed' on board the car to liberate hydrogen gas for the fuel cell.

But for each 10 litres of methanol you consume, you have about three kilograms of carbon left over.[2] You would have to store the carbon aboard your car, as a solid or powder, and empty it out when you fill up again at a roadside filling-and-emptying station. The carbon you empty out would be gathered up and returned

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[1] J.M. Weingart, 'The Helios Strategy', *Technological Forecasting and Social Change*, Vol 12, No 4, 1978. An extract appears in Richard Rhodes, *Visions of Technology*, Simon & Schuster, 1999, pp 323-8: 'Operation of solar energy systems and the infrastructure required for their construction and replacement will have environmnetal consequences, in spite of some widely prevailing myths that solar technologies will be relatively benign. We know that new technology, when used on a large scale, can often have unexpected and sometimes unwanted consequences... Fragile desert ecosystems would be severely impacted during construction, with fine desert crust broken, leading to erosion and dust. The habitats of burrowing animals would be destroyed and the ecology of the region permanently altered. While on the national scale, additional air pollution resulting from production of glass, concrete and steel for the solar plants would not be substantial, the local impact of these emissions would constitute an environmental charge against the facilities.' The time scale for reaching an industrial level is a century.

[2] For the American reader: for every five gallons of methanol you consume, you are left with about 14 pounds of carbon.

[3] Except for the quantities involved, recycling petroleum products is not an especially revolutionary idea. You change the lubricating oil in your engine from time to time; the old crankcase oil (five litres - about a gallon) is stored at your garage or service station and eventually collected and recycled for less critical uses.

somewhere to be got rid of;technically, we call it sequestration.In other words,the production and distribution of methanol as a fuel for a hydrogen fuel-cell car would have to be accompanied by the recovery and sequestration of the residual carbon.

In another such scheme, the carbon residue of the 'reformer' is graphite powder. Graphite is totally inert and should not contaminate the biosphere. It might be dumped in a landfill or in the sea. Industrial uses might consume a small amount.

There are other schemes. In each case the hydrogen is chemically bound and released in an on-board reformer.The chemical residue must be taken care of – in some schemes it is sent back to the factory to be recycled and recharged with hydrogen.[3]

Doing the sums

At this point, it is convenient to begin to think quantitatively. Petrol is transported across the seas in gigantic tankers of 100 000 tons,250 000 tons and even 500 000 tons. Pipelines are much less spectacular than an oil tanker the size of a football field, but the quantities transported are similar. In the United States,coal is sometimes brought from the mine in 'unit trains' comprising 100 cars about a mile long – say 5,000 tons a trainload. A 1,000 megawatt power plant would consume a trainload a day.

The world currently consumes 70 million barrels – about 10 million tons – of oil a day, the contents of 20 to 50 gigantic tankers. Fortunately a substantial fraction of that oil is transported by pipeline. But we would have to deal with comparable amounts of carbon, perhaps in the form of graphite (about 8.5 million tons a day) or carbon dioxide (about 30 million tons a day).

In a recent year (1993),France consumed about 80 million tons of oil, about 220 000 tons (one giant tanker) a day. Burning that oil released about 190 000 tons of carbon into the atmosphere per day. If all that carbon were sequestered as graphite, say, and carried away by train, it would fill 10 000 railroad cars a day, making a train 100km long.[4] The useful energy provided by that much oil is 900 GWh per day – about the same as the daily production of nuclear energy by France's 59 nuclear reactors.

The nuclear alternative

A nuclear power station emits no CO_2, so if we make the hydrogen to run our fuel-cell cars by using electricity from a nuclear power station, then there is no emission of CO_2.

Where does the uranium come from? Like everything else the earth is made of, uranium is a remnant of a supernova (the explosion of a giant star),which occurred about five billion years ago, just before our solar system was formed. In fact, the entire solar system is formed of the debris of such stellar explosions. Uranium too is mined, and mineral resources of uranium-235 will last 100 years or more. With advanced reactor systems, thorium and uranium-238 can be converted to useful fuel and made to last 50 times longer.[5,6]

For our purposes, the essential property of uranium as a source of energy is that it is compact – its energy density is about ten million times greater than the energy density of fossil fuels. Thus for the same amount of energy, the volume of nuclear fuel is about ten million times smaller than that of fossil fuel,and the volume of the end product is correspondingly ten milliion times smaller.

In France 80% of the country's electricity is nuclear. In 1993, Electricité de France produced 368 188 GWh of nuclear electricity, about 1000 GWh per day. To produce that electrical energy, EdF consumed about 135 kilograms of U-235 per day, 50 tonnes per year (the U-235 content of about 7000 tonnes of uranium).After fission,one is left with very nearly the same weight of radioactive fission products. Most of the radioactivity is short-lived, and spent fuel elements are allowed to 'cool' for a few years on the site of the power station so that the short-lived radioactivity decays. Only then does one chemically separate the long-lived radioactive materials for sequestration, but by then they represent no more than 20 kilograms per day, say seven tonnes per year.

I do not underrate the technical problems of handling and disposing of the long-lived products of radioactive fission, whether by burial or

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4 Spread out over the ground to a depth of one metre, the graphite so produced in France each year would cover about 35 square kilometers or 3500 hectares (about 14 square miles or 9,000 acres). For comparison, the area of Paris is about 100 km^2.

5 Robert H. Romer, *Energy Facts and Figures*, Spring Street Press, Amherst, MA, 1985, p27. Known economic reserves of uranium are some tens of millions of tonnes. In the very long run, uranium might even be recovered from sea water, where its concentration is three milligrams per cubic metre; there are about four billion tonnes of uranium dissolved in the seas. Romer has also pointed out (p44), that 'Rocks containing low grade thorium deposits are found near the surface in many parts of the world. As an example, the Conway granites in New Hampshire, covering an area of about 750 km^2 and probably extending to a depth of several kilometres, contain 150 grams of thorium per cubic metre. Down to a depth of one kilometre [the Conway granites] thus contain approximately 100 million tonnes of thorium.'

6 In developing its as yet unannounced nuclear weapons programme, and especially to be sure that it would be independent of foreign suppliers of uranium, Israel planned to fuel the Dimona plutonium production reactor, with uranium extracted from abundant domestic phosphate deposits. Avner Cohen, *Israel and the Bomb*, Columbia University Press, New York, 1998, p 179.

incineration. Yet despite these – and the no less formidable political problems – I submit that it is much easier to separate and store nuclear fission products than to sequester the corresponding quantities of graphite, CO_2, and whatever other residues may be derived from burning fossil fuels for the hydrogen fuel-cell economy. It is also immeasurably less damaging to the atmosphere and ecosphere. Just one of several reasons why I am an environmentalist for nuclear energy.