‘H_2 for C’: Might substituting hydrogen for fossil fuel reduce global inequalities in health? [1]

ABSTRACT

Should public health focus again, as it did a hundred years ago in the UK, on the environment? The focus would now be on use of energy. Biomedical interventions have tended to favour countries and classes with superior economic and cultural capital. Economic growth has not necessarily compensated for this, because wealth has not trickled down on the whole from rich to poor. As a result inequalities in health persist.

The article focuses upon evidence for three processes by which the world's dependence on fossil fuels contributes to inequalities in health. They are differential exposure to: 1) poor air quality, 2) climate change following global warming, 3) war and terrorism associated with the geopolitics of fossil fuel. The article pursues the argument that a future hydrogen economy is likely to reverse these processes.

On the other hand, a change of technology alone would leave intact socio-economic structures that are in themselves sources of inequality in health and so would not 'solve' the problem in all respects.

‘Health inequalities’ are systematic differences in life expectancy and healthy life years by such possible sources of unequal opportunity as class, gender and ethnic group (Bartley, Blane, & Davey Smith**,** 1998). The differences are both social – they happen between categories within society - and spatial – they divide regions. Reducing spatial and social inequalities in health together is the focus of this paper, for the means envisaged is a change in the environment occupied by poorer people.

The account is interdisciplinary and so must start with background on both public health today and hydrogen technology. Section 1 follows, asking to what extent and by what means substituting hydrogen for carbon-based fuels (H_2 [2] for C) might reduce inequalities in health. Section 2 asks whether other alternative scenarios than those involving H_2 energy might have similar or different effects on health inequalities to an H_2-economy. Section 3 poses the question of whether substituting H_2 for C might fail to address all the underlying determinants of health inequalities or might be compromised if those economic, social and cultural factors were not changed.

Background

Whither public health?

From the middle of the 20th century, interventions to improve public health have been led by a biomedical approach, informing epidemiology and health education, rather than by an environmental approach. This is in contrast to the 19th and early 20th centuries, when the environmental approach was dominant. Since then, of course, there have been substantial improvements in the treatment of disease by surgery and medicine. Many infectious diseases have been brought under control and some, such as smallpox, have been eliminated by immunisation. There have also been successful programmes to screen then treat populations for risk factors and to educate the public about risks to health.

Yet biomedical interventions are often expensive and depend on infrastructure and education levels that tend to be weak in poorer regions of the world. Within each nation state, rich or poor, the richer members of the population have tended to benefit more quickly and sometimes more in the long term than the poor.

A change in direction in public health is discernible in the 21st century, but it has yet to take a clear identity. As the historian of public health, Simon Szreter 2002), has pointed out: ‘the current generation of public health practitioners are having to reconstruct [a redistributive social philosophy and practical politics] following its virtual dismantlement during the last two decades of the 20th century.’ It was ‘virtually dismantled’ about thirty years ago. Thus, Thomas

McKeown (1976), minimised the impact of intervention in any form, biomedical or otherwise, on the fall in death rates that had brought about the ‘modern rise of population’ in Britain, which he dated to the first fully reliable figures on births and deaths (1838). He claimed that the main gains came before biomedicine was effective. Cures were practically non-existent and only one early preventive measure had worked and then on a small scale: it was smallpox vaccination. Investment in public sanitation came too late and was thus secondary. He implied that Adam Smith’s ‘hidden hand’ of market-driven economic growth outranked all other possible explanations. In Britain, the rise in the standard of living during the agricultural and industrial revolutions of the 18th and early 19th centuries, especially how much people had to eat, had a marked effect on resistance to infection and thence mortality at all ages and among poor as well as rich.

McKeown’s account of the chronology and causes of the undoubted improvements in population health in 19th century Britain has been criticised effectively elsewhere and that critique does not need to be repeated here. Szreter (1988) and others have questioned the extent to which ‘trickle-down’ of wealth was sufficient to improve the health of the poor and have rehabilitated the contributions that earlier historians had attributed to public health-driven environmental change during the late nineteenth century. These revisions of McKeown’s thesis have not, however, rehabilitated the contribution of biomedical intervention in that period, which was small.

After the mid 19th century and for many years after Pasteur's and Koch's path-breaking laboratory work on micro-organisms in the late 19th century, public health intervention was primarily about water, sewerage and housing (Latour, 1988). These measures reduced the risk of communicable diseases for rich and poor alike. Indeed they were initially targeted at areas in which the poor lived, in the (mistaken) belief that 'miasma' gave rise to communicable diseases and emanated from poor areas. Might non-fossil fuel be the equivalent key to improving health during the 21st century, especially in poorer areas? Might the latter day solution to health inequalities lie not with medicine but with science and engineering, as it did a hundred years ago?

Hydrogen as energy of the future

Substituting non-fossil for fossil fuels, such as oil and natural gas, would enable global capitalism and the energy-intensive way of life it entails to be continued as and when fossil fuels run out (Jones, 2003). At the same time it would improve the environment and the health of the population.

The appeal of H_2 lies largely in its ability to substitute for oil in fuelling transport or for oil and natural gas in heating and industry, so mitigating an increasing source of both air pollution and greenhouse gases.[3] However, an H_2-economy would only be sustainable well into the future, if H_2 were generated from renewable sources, such as biomass and wind, marine and solar power, or else from nuclear fission.

Much of the commentary about substituting H_2 for fossil fuels tends to be utopian, but an H_2-future is by no means a new idea (Verne, 1872), and it has to be asked why it has been so slow in going forward.[4] It is also vital to be aware of where H_2 for C might leave problems untouched or create new ones (Cherry, 2004), and to recognise that a large change such as this can take several courses. Whichever transitions to an H_2-economy are first attempted may make or break the long-term project (Sørensen, Petersen, Juhl, Ravn, Søndergren, Simonsen, *et al.,* 2004; Kruger, Blakeley, & Leaver, 2003).

H_2 is the most abundant element. It has the lowest atomic weight, and, at normal temperature and pressure, is a low-density gas of high volatility.[5] Yet H_2 exists in nature as a free element in only small proportions. Considerable energy is needed to 'generate' H_2, transform it to a state in which it can be stored for delivery for work and, finally, turn it into work.

H_2 is envisaged in Figure 1 as an energy carrier in a cycle of electricity generation: at the end point electricity converts energy into work.[6] The role of H_2 may involve either central or local generation of electricity. Central generation involving H_2 would feed into the electricity grid. Local generation might be a small-scale installation from which local users fed or an on-board vehicle/on-site application for each user. Because electricity is also an energy carrier that has to be generated from primary sources, use of H_2 in the complete cycle involves one or more conversions. In each some energy will be 'lost', i.e. efficiency will be lowered. There have to be other gains to compensate for this loss.[7]

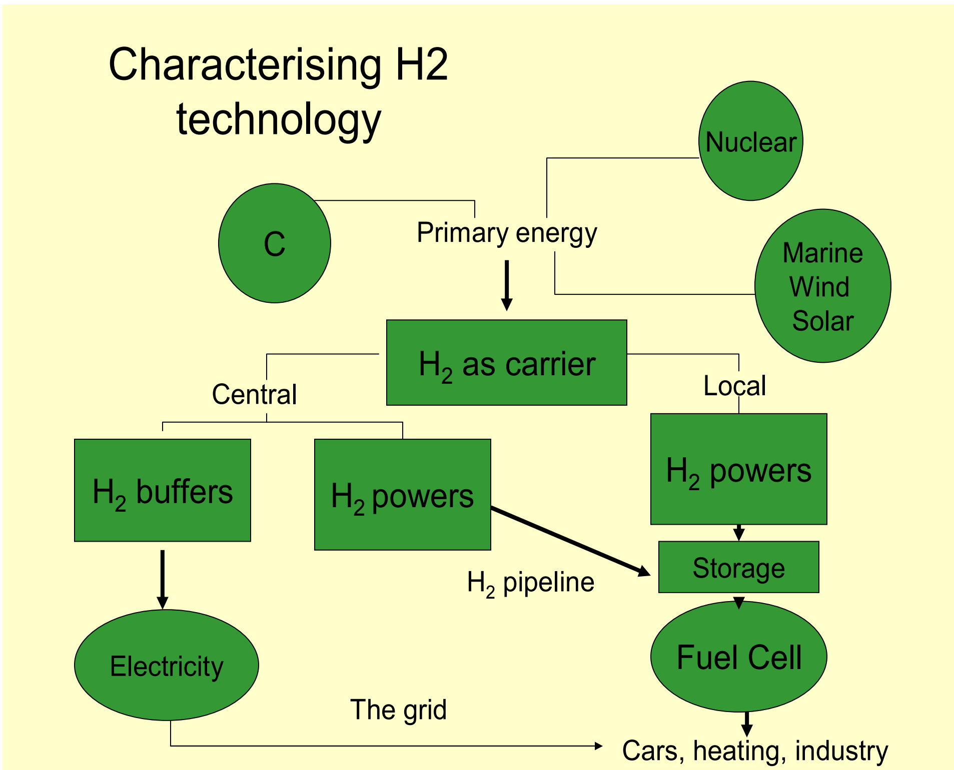

Figure 1 Characterising H_2-technology

For local installations, such as commercial garages, and especially for use on-board vehicles, compact, light storage of H_2 is needed that allows rapid access to enough of the gas to meet likely demand. On present knowledge, this would involve light metal hydride or carbon stores that are in course of development.[8] Currently, storage of H_2 requires either cryogenics, i.e. liquefaction at low temperatures, or high pressure. Both are energy intensive. In either case strong containers are needed that are both bulky and heavy. At present they can only be filled safely at a well-regulated plant or filling station, not in a domestic garage.

Security of supply of fuel

Security of supply drives much of the debate about fossil fuels. Carbon is fundamental to all organic matter, is normally a solid and is sixth in the atomic table. Like H_2 it is abundant and occurs combined with H_2 in such fuels as wood, coal, natural gas and oil. Wood and other biomass can be renewed,[9] whereas oil is a fossil fuel, product of non-renewable organic matter lying in carboniferous sediments formed 360-290 million years ago.

Among non-renewable fossil fuels, there are still large reserves of coal but natural gas and oil are much less abundant. Oil and natural gas, not coal or biomass, are the most significant C fuels in use today, especially in developed countries. Known world natural gas reserves are within some 60 years of exhaustion at current rates of consumption, though it is likely that others will be found. Known world crude oil reserves (that it is economic to exploit) are within 36 years of exhaustion at current rates of consumption. The largest shares of proven reserves of oil (about two thirds) and of natural gas (about two fifths) are in the politically volatile Middle East (www.ott.doe.gov/facts/archives, http://earthtrends.wri.org). Unless the present sharp rise in consumption of oil and gas (led by China and India) is stemmed, the known reserves will run out much quicker than this suggests. It may be assumed that world prices of crude oil and natural gas would increase year on year well before reserves ran out.

The balance of reserves, production and consumption is extremely uneven across the world. Thus in 2002 the United States was responsible for 2% of world crude oil reserves and 9% of petroleum production, yet consumed 25% of all the oil produced. It was responsible for 3% of the natural gas reserves, but 26% of the consumption. Between 1965 and 2000 its consumption of oil rose from 12 to just under 20 million barrels per day, and its production fell from a peak of 12 million a day in 1970 to less than 8 million in 2000. Thus it has long been dependent on imports and every year becomes increasingly so. This will apply increasingly to the United Kingdom.

Section 1:

Public health impacts of the C-economy and of substituting H_2 for C

There seem to be three mediums through which a C-economy might produce health inequalities: air pollution, global warming and geopolitics. Air pollution has a relatively direct impact on human health, whereas adverse effects on health arise indirectly from global warming and geopolitics. Moreover, the effects of air pollution are more understood, less controversial and better documented than either of the others. In all three areas, there is a case that substituting H_2 for C would greatly diminish the adverse effects on population health and also the health inequalities that are associated with the C-economy.

Air pollution

In its various forms – coal, oil, natural gas, biomass – C has to be burned in oxygen to produce usable energy, and is usually burned in air, which is a mix of gases. The emissions in air typically include CO_2, CO, NO_2, NO_x and particulate matter (unburned C particles of varying size). Coal, which contains sulphur, also produces SO_2 and gasoline produces O_3 (ozone). Some of these emissions have been reduced by regulations and redesign of the combustion process. Many are implicated in respiratory and cardiovascular conditions.

In an Act of 1956, the UK introduced a 'clean air' policy, following severe 'smog' in London in 1952 that was attributed largely to coal burning. The target was smoke, that is, visible emissions rather than invisible. Thus smokeless fuels were seen as acceptable substitutes for raw coal. The substitution of natural gas for coal in domestic heating, industry and power stations enabled the policy to be realised and latterly has contributed to reduced greenhouse gas emissions.

A recent study that implicates 'clean air' in health improvement is an assessment of the impact on population health of the change in the ambient air quality of Shanghai, the biggest city in China, as polluting industries were relocated and superseded by services in the decade 1990-1999. The authors (Chen & Kan, 2002) show that TSP (total sampled particulates) and SO_2 levels fell. On the other hand, traffic-related NO_x levels increased. They estimate that avoidable deaths from high TSP levels fell by 78-80% in the decade.

In spite of an earlier reduction in TSP levels in the UK, there has been an increase in the reported incidence of asthma since. An expert committee in 1995 (Department of Health,1995) reported from the evidence within the UK at the time, that outside air pollution has no bearing on this increase, because outside air pollution has improved. However, ‘smog’ has been reborn, as the haze, often almost invisible, that hangs over areas of high traffic and residential density, especially in warm, sunny conditions. Climate makes the palpable appearance of this new form of smog more likely in parts of the USA than the UK, and it is in the USA, notably California, that the earliest and most strenuous attempts have been made to reduce emissions at source, especially from internal combustion engines.

Among the several pollutants arising largely from traffic is one that can be readily measured on site: the concentration of *small* particulate matter - less than 10 microns in size per cubic metre (PM10). A study of PM10 in the eight largest cities of Italy (Glassi, Ostro, Forastiere, Cattani, Martuzzi, & Bertollini, 2000) concludes that reducing average PM10 concentration to 20⇐g/m^3 would save 5,500 lives a year in Italy. The clinical causes of such deaths include asthma, acute and chronic bronchitis and cardiovascular disease. Another study, again of eight cities, but elsewhere in Europe, finds that daily variations in PM10 concentration are positively associated with daily admissions to hospital for respiratory conditions among children and younger and older adults alike

(Atkinson, Anderson, Sunyer, Ayres, Baccini, Vonk, et al., 2001). A still more recent finding, released to the press on 20 February 2005 by the European Environment Agency, is that the number of deaths throughout the European Union from the particulate matter emitted from vehicles greatly exceeds both past estimates and also the number of deaths from road accidents: the latter by a factor of *nine* in the UK (*Independent on Sunday*, 20 February 2005, p2). In their earlier assessment of the public health impact of outdoor and traffic-related air pollution in Europe, Kunzli, Kaier, Medina, Studnicka, Canel , Fillger et al. (2000), concluded that outdoor air pollution accounted for 6% of total mortality and that traffic-related air pollution accounted for half of this and, in addition, more than 16 million person days of restricted activity.

Arguably, using fossil fuel contributes to health inequalities, both between rich and poor countries and also between classes in the two types of country. Exposure to air pollution from combustion of coal prevails to a greater or lesser extent in China and other rapidly industrialising countries. This is a factor in inequalities in health between countries (World Resources Institute, 1988-9). Air pollution *indoors* is a factor in health inequalities within those countries that are most undeveloped. The poor depend on biomass (wood, dung) for cooking and heating in confined living quarters without chimneys and they and their children are liable to respiratory disorders that rich households avoid. In the developed world, where the products of burning oil in vehicles pollute the air, it tends to be those who live in inner cities and are exposed thereby to high traffic densities that are most at risk of respiratory conditions and avoidable deaths (Mortimer, Neas, Dockery, Redline & Tager, 2002). They are relatively poor, for the affluent often remove themselves to the suburbs or the countryside.

Global warming

Most of the products of burning C are direct human health hazards, except for CO_2. If not absorbed naturally by plants or the sea, or not deliberately sequestered (say, in exhausted oil wells), CO_2 is a 'greenhouse gas' that envelops the earth in the upper atmosphere, so trapping in the radiant heat of the sun. It is vital for life that the upper atmosphere should blanket the earth. Nature itself contributes to greenhouse gases, because organic decomposition produces methane and carbon dioxide. The majority scientific opinion, however, is that increases in the CO_2 element due to intensified burning of C as fuel have led to progressive rise in temperatures globally since the late 19th century (Nicholls, Gruza, Jouzel, Karl, Ogallo & Parker, 1996). While this claim remains controversial[10], nearly all projections for future increases in global temperature register positive. An international conference organised by the UK Department of Environment, Food and Rural Affairs in Exeter on February 1st to 3rd 2005 lent credibility to claims previously made by the Intergovernmental Panel on Climate Change Third Assessment Report (2001).

A rise would have differential effects on minimum and maximum temperatures by region, depending on the altitude and latitude, whether the region were landlocked or by the sea, and the flow of hot or cold sea currents around its shores. Changes in climate affect what crops can be grown, what livestock can be kept and which wild life may flourish. Any disruption to patterns of hunting and gathering, fishing and agriculture could undermine the sustainability of traditional ways of life that depend on them, and have adverse effects on the health of the people involved. Science- and technology- based agriculture in developed countries may be more adaptable, and in any case accounts for only a tiny proportion of the population. This suggests that rising temperatures would widen global health inequalities.

The hypothesised effects of global warming on climate include increases in extreme events, such as floods, droughts and tornadoes (Mearns, Katz & Schneider, 1984). The areas most likely to be affected are the tropics and also the poorest parts of the world, such as sub-Saharan Africa, South and South East Asia, the Caribbean and Central and South America. However, most of the data on extreme events (and most of the media coverage) is in the temperate zone, especially the United States, rather than worldwide, and so the climate effects of global warming remain more speculative than global warming itself (Easterling, Evans, Groisman, Karl, Kunkel & Ambenje, 2000).

Global warming is directly related to the volume of C that is burned. It is rich countries that disproportionately produce global warming and give most attention to air pollution in their own boundaries. It is poor countries that endure the worst of air pollution, especially as they begin to industrialise, and may in the future endure the worst effects of global warming. The burning of H_2 itself produces no CO_2. The gains for global warming in substituting H_2 for C should thus reduce health inequalities too.

Geopolitics of fossil fuels

As noted earlier, large oil and natural gas reserves are not necessarily to be found in the developed countries. This implies that economically powerful countries have an interest in securing their supplies. The relatively few developing countries that are oil producers have some countervailing power and the capability to generate wealth. But non-oil producers that are not economically powerful are at the mercy of the trade balance struck between the first and the second categories.

Moreover, since the rich but oil-import-dependent countries of the West are militarily dominant, they are tempted to secure their interests by manipulating the governments of the oil-producers and, if they think it necessary or expedient, by going to war with them.

Though relatively neglected in current public health literature, war is a major cause of premature death, disability, nutritional deficits and communicable diseases (Horton, 2003; Toole, Galson & Brady, 1993). Though many deaths are of serving military, modern warfare is even more destructive of civilian life than traditional warfare. Civilian deaths reported following the invasion of Iraq by the USA and its allies, have accumulated to between 27,115 and 30,559 at the time of writing (Iraq Body Count November 30, 2005 – however, the degree of under-reporting is considerable). Military fatalities in the coalition totalled 2,195 in the same period.

Resistance to overwhelming military might by the relatively weak tends to take guerrilla forms. ‘Terrorism’ is one variant. It too is destructive of civilians.

Substituting H_2 for C could have an impact on the geopolitics of energy, that is, on the balance of economic power and the associated likelihood of war and terrorism. Since economic power, war and terrorism have health impacts of their own, the substitution of H_2 for C could well contribute by these means to a reduction in health inequalities between and within countries.

The advantages of H_2 geopolitically are that it is ubiquitous and can be produced from several primary energy sources. The plant to generate H_2 would be a necessary capital investment, as would means of distribution and fuel cells to convert hydrogen into work. But no country could have a monopoly of the primary energy reserves. Virtually every country could produce as much H_2 as it consumes. For instance, in the UK, with its long coast-line, marine generation seems especially promising; whereas in sub-Saharan Africa, solar power seems so; and in Iceland the geothermal power of active volcanoes.

Section 2:

How might H_2 energy systems compare with others that substitute for C?

As Figure 2 suggests, H_2 might or might not be part of a future energy system that substitutes for C. To eliminate C at any point in the system, H_2 would have to be generated by one or more of the alternative primary sources. They fall into two classes. The first is nuclear power. This is tried and tested. In OECD

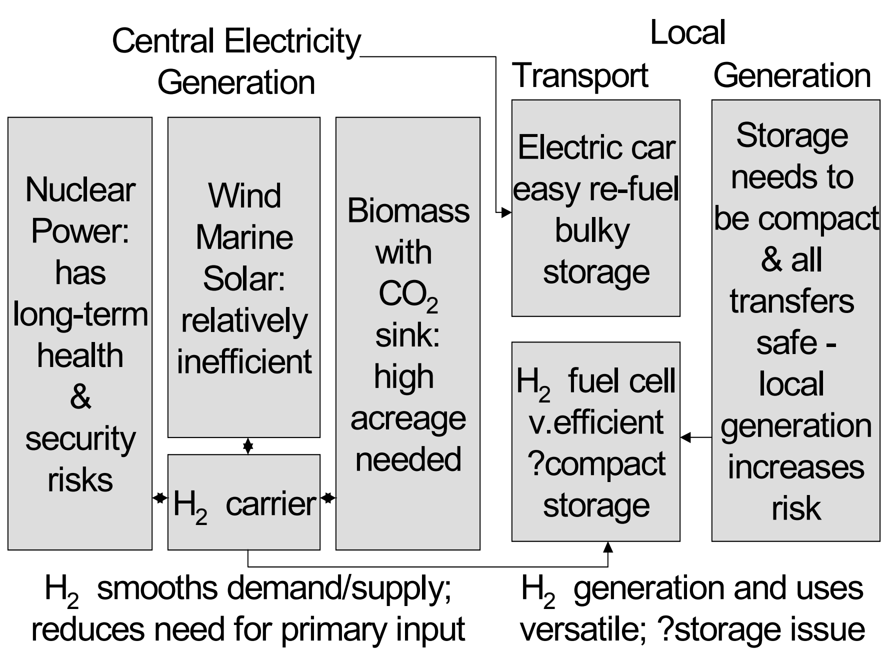

Figure 2 Why H_2?

countries in 2002, 22% of electricity generation was by nuclear fission: in the UK it was slightly higher than the average (24%), but in France much higher (78%) (Nuclear Energy Agency, 2003). The second set of alternatives is renewable sources, such as wind, marine and solar power, and also biomass (carbon-based and yet renewable).

Security of supply

While wind, marine and solar power are renewable, they produce energy intermittently and not in synchrony with demand, and so the number of installations required if they were to match current energy needs directly is very large and would occupy large tracts of countryside or coastline. Growing biomass to meet current demand for energy would also involve committing large acreages, both for primary energy and as a sink for the CO_2 that combustion and fermentation of biomass both produce.

Nuclear fission is secure in the long term because of spent fuel reprocessing, even though the radioactive materials required are in the earth's crust and finite in supply. It is also much more compact than marine, wind and solar modes of generating electricity. Rising oil and natural gas prices would make its current high costs of production more economic.

Producing electricity for static applications would almost invariably be more efficient and economic than producing H_2 for subsequent conversion to electricity at the point of use (DTI 2004). Nevertheless, using H_2 generated by renewables or by nuclear power as a buffer in the energy cycle would reduce dependence for energy supplies on these primary sources. H_2 driving a fuel cell would already serve better than electricity stored in batteries if consumers wished to preserve the high performance they expect of personal transport, and would serve better still when lighter and more compact on-board storage of the gas is achieved than at present.

Clean air

With the partial exception of using biomass as a fuel, other renewable sources that are currently debated have no adverse effect on air quality. This applies to wind, marine and solar power. The same applies to nuclear power. However, its radioactive material is a long-term health hazard. It degrades only very slowly, and so decommissioned plant can be more of a hazard than fully functioning plant. The cost of making it safe is one of the factors that give nuclear power a higher price than that of natural gas (and coal) in the present day UK energy arena. Radioactivity is implicated in cancer.

In the current and perhaps foreseeable state of the art, only H_2 and solar power could be on-board power for terrestrial transport vehicles. Otherwise, electricity generated centrally by wind and marine, biomass or nuclear power would have to be fed by power lines to trains or stored in batteries carried in moving vehicles. The only exception to date is ships, which have been propelled successfully by nuclear power generated on board. Airplanes are a major contributor to pollution and also global warming. They cannot be driven by battery-stored electricity or on board nuclear reactors but H_2 probably could power gas turbine engines.[11]

Since use of fossil fuels in transport contributes greatly to air pollution, substituting H_2 for C may be the most practical way of eradicating this problem.

Global warming

Substantially similar things can be said about the respective merits of using H_2 and using renewable or nuclear sources of power directly, in connection with energy-related CO_2 emissions and the global warming process that they have propelled.

On the other hand, leaks of H_2 in the course of its generation, distribution and use, given the high reactivity of the element, could contribute to global warming by combining with other elements in nature to form greenhouse gases such as methane (Tromp, Shia, Allen, Eiler. &Yung, 2003). Escapes into the upper atmosphere may also damage the ozone layer that protects the earth from ultra-violet radiation, a cause of melanoma in humans (*New Scientist*, 15 November 2003). Thus, some of the environment and health gains that have been attributed to H_2 may be compromised, if the tendency of volatile H_2 to leak from pipelines and containers is not held in check. This is a major technological challenge, given that H_2 is the lightest and least dense of all elements.

Geopolitics of renewable sources and nuclear power

Wind, marine, solar power and biomass sit alongside H_2 in being virtually ubiquitous. However, the fissile material used in generating electricity by nuclear power is scarce and also has military applications. Its transport from site to site is a security risk and at least as much a cause for conflict as is access to oil reserves. It has been noted that war and terrorism are major public health issues and their adverse effects fall disproportionately on the poor.

Summary

By using other non-fossil sources of energy to generate H_2, waste can be reduced in central electricity generation and the most can be made of whatever natural resources a country has. H_2 is also more competent in powering vehicles than alternatives. It would permit continuation of a way of life that includes cars and airplanes. Poorer countries and poorer people in developed and developing countries aspire to this life style. Arguably, they should not be deprived of its benefits.

The benefits to health inequalities of a wholesale substitution of H_2 for C are probably superior to those that would follow exclusive reliance on other alternatives to fossil fuels. But that is not the whole issue. It is necessary to determine the extent to which substituting H_2 for C leaves untouched other causes of health inequalities than the C-economy itself.

Section 3:

What aspects of health inequalities would *not* be changed in substituting H_2 for C?

Whatever its benefits, substituting H_2 for C would probably leave unchanged many of the features of the current economy, polity and society. Some of these help sustain health inequalities. Some of them might also inhibit the complete substitution of H_2 for C. They include the public's perception of risk, continuing traffic congestion, global corporate capitalism and inequalities of income and wealth.

Risk in public perception

Along the way, safety may become a problem for H_2's acceptance by both consumers and governments. H_2 is explosive in air in a confined space, where it cannot, as when in the open, fly rapidly into the upper atmosphere. The public is largely ignorant of the concept of an H_2 economy at present. This could cause it to amplify any threat H_2 seems to pose, for instance if a local explosion did occur as a result of a leak in a confined space (Bellaby, Flynn & Ricci, 2004, Flynn, Bellaby & Ricci, 2005). There are or have been associations of H_2 with the Hindenburg airship disaster and the H-bomb. Re-evaluation of the Hindenburg disaster data suggests that the H_2 gas stored on-board for buoyancy is unlikely to have caused the fire that consumed the airship (Bain &Van Vorst, 1999). The hydrogen bomb is irrelevant to the use of H_2 as fuel. However, popular beliefs might impair public acceptance of the idea of substituting H_2 for C, even though fossil fuels themselves carry widely known risks to safety.[12]

Should it escape, H_2, unlike gasoline, does not leak out onto the ground in the open air where it may be ignited by a spark. Instead it escapes upward and, if it does ignite, burns upward. On the other hand, as with gasoline, actual safety depends on implementation in practice of build and operational standards which engineers consider safe (http://(www.hydrogensociety.net/hydrogen). The more localised the generation, storage and delivery for use, the greater the number of ways in which safety may be compromised.

Making H_2 for C acceptable to the public will no doubt entail satisfactory regulation of the health and safety risks associated with H_2 (Dorofeev, 2003). On past evidence, it is probable that resistance to locating H_2 generators, storage depots or fuelling points will arise in affluent rather than poor areas, with the result that any actual risks associated with H_2 will be visited on the poor.

Regulation has other faces in the energy arena, notably in electricity generation. In the UK as in the USA, it takes the form of industry-wide regulation of terms of supply to the grid and delivery to the consumer, including price. The public wants energy that is both safe and cheap. It also wants energy supply that is sufficient to meet (fluctuating) demand and reliable - not likely to break down. Safety, reliable supply and cheapness are somewhat competing objectives. A failure of the electricity generation and distribution network in North America in 2003 was interpreted as implying that interventions by the state to force down prices might imperil the economic viability of maintaining adequate generation and distribution capacity by commercial suppliers (Rosenzweig, Falk, Voll & Fraser, 2003).

Cheap energy favours the poor. The greater the health and safety regulation required to make H_2 safe and secure its supply, the higher the price to the consumer is likely to be. On the other hand, the more market regulation forces prices down, the less likely may be commercial investment in the necessary infrastructure and so the transition from a C-economy to an H_2-economy.

Continuing traffic congestion

A full H_2-economy would not be less energy-intensive than is the current C-economy. It might enable developed countries to continue their way of life when fossil fuels ran out and developing countries to continue to catch up with them. This could be an incentive to take the H_2-route. If the adverse effects on public heath and the environment that go along with fossil fuels are eventually to be removed, is there any reason left to resist a high-energy economy?

One reason may be progressive congestion on roads and especially in cities by private cars, and in the air by planes, should H_2 be adopted for all traffic. If, by enabling traffic congestion to grow, H_2 for C makes cities prohibitive to their inhabitants and concretes over the remaining countryside, the change could be a mixed benefit: offsetting gains made for environment and human health by reducing pollution, global warming and war, with losses in the extent of the green environment itself and consequential effects on climate and bio-diversity.

The continuation of global corporate capitalism

There is commercial interest in developing H_2-technology, which will no doubt be sharpened as reserves of natural gas and oil deplete, but there has to be doubt about whether, left wholly to themselves by the state, these will drive forward or impede the transition to an H_2-economy and the reduction in health inequalities it promises.

While several large car producers and oil companies are investing in R&D at the moment, the proportion of their R&D that is in H_2-technology is small. On the whole, the commercial interest is in development of technologies that can be patented and so exploited while the patent runs and gives the owner a competitive edge. This tends to restrict the dissemination of knowledge. Though fuel cells seem to be well on the way to production on a commercial scale, basic research is needed in several areas, especially sustainable and efficient ways of generating H_2 and, above all, for transport uses, light, compact, safe and cheap ways of storing H_2 on board vehicles.

Basic research of this kind is more likely to be done in universities than commercial firms. Much of the research would need public money. In the UK, the outlay for basic research on H_2-technology is increasing but remains modest, and, while what the USA has committed to this cause is vastly greater, it remains small in comparison with the total R&D outlay in the country, especially on defence.[13]

It is also the case that commercial interests may impede the development of H_2-technology. Investing in H_2 requires vast disinvestment in fossil fuels – in production, networks for distribution and means of converting the fuel into work. Of course, firms that can vary their structures and technologies to encompass the new are likely to hedge their bets and invest somewhat in developing H_2-technology in order not to be caught out at some future date. This does not mean that they are in a position to race ahead with the substitution of H_2 for C. Rather they may wish to slow the process down so as to make the adjustment less costly and risky for themselves.

Thus the benefits that might flow to health inequalities from substituting H_2 for C may be imperilled by the rational economic behaviour of individual firms in an oligopoly market.

Inequalities in income and wealth

It has been argued here that if H_2 were substituted for C, inequalities in health would be reduced, both globally and within countries. This is not because inequalities of income and wealth will diminish as a direct result. Rather the medium term effects of the change in infrastructure upon health will be diffused, falling on rich and poor alike and benefiting the poor more because they are more likely to suffer the ill effects of the C-economy. In this sense, the impact of H_2 on a society based on fossil fuels would be similar to that of the investment in water, sewerage and housing that characterised public health reform in the late 19th and early 20th centuries.

If inequalities in income and wealth are untouched by a switch in energy, they could continue to exert an effect on variations in health. The mechanism might be direct (in the sense that poverty might cause ill health) or it might be mediated. Some have argued that social inclusion/exclusion mediates the impact that inequalities in income and wealth have upon health. If social cohesion is impaired and social exclusion increased for the poor when inequalities of income and wealth are wider, then inequalities in health might be wider too.[14]

Deployed at the micro-level, H_2 has been called the 'democratic' fuel of the future, in other words a fuel that would reduce social exclusion and empower individuals of all social categories (Rifkin, 2002). The scenario this suggests is highly decentralised generation, storage and application of H_2 in which 'regeneration breaking' can take place - in effect, each household, wherever it is in the world, would be its own power station contributing to production as well as use of H_2.

The initial obstacle to implementing this project and so reducing social exclusion would be its high cost to the final user. This ‘democratic’ pathway to the H_2-economy might prove inaccessible to the poor. If costs did not come down, the poor might remain dependent on fossil fuels. As the costs of fossil fuels rose, more of the poor would lose the means to run their own cars. Thus, far from reducing social exclusion, increasing social cohesion and thereby reducing health inequalities, a high cost entry to the opportunities H_2 energy opens might actually increase social exclusion.

At the whole-society level, using H_2 as energy carrier in the central generation of electricity from primary sources of energy might proceed without the same degree of impediment from the existing distribution of wealth and income. Countries would have to be able to afford the plant for generating electricity, using H_2 as a buffer, but lower running costs might offset the capital cost.

Conclusion

Public health as science has to break from undue reliance on both the biomedical approach and also its antagonist - the view that accumulated wealth can trickle down and deliver the poor from ill health. It must explore with renewed intensity environmental causes of inequalities in health between populations across the world and within the societies formed by these populations.

The worldwide use of C as fuel - specifically fossilised organic matter – appears to be among the environmental causes of health inequalities. Its effects are likely to be mediated by the air pollution and global warming it induces and the geopolitics of the distribution of the fossil fuels most in demand and shortest in supply – crude oil and natural gas. It seems likely that substituting H_2 for C would remove carbon's adverse effects on health inequalities, by influencing each of these mediators.

At the same time, if a purely technological change, H_2 for C would leave many of the causes of health inequalities untouched. The critical ones are inequalities of wealth and income, the exploitation of the commercial potential of new technologies by multi-national corporations and increasing traffic congestion. These social dimensions of the energy economy could impede the transition from carbon to hydrogen.

Whatever course is set towards an H_2-economy is likely to prove decisive for its eventual realisation. Nation states and regional and global trade agreements will have to give the transition a strong steer, by providing incentives for both R&D in H_2-technology and also for consumers to prefer H_2 to C. It has also been suggested that some improvements could be gained along the way in health inequalities by focusing immediate attention on the use of H_2 as energy carrier in the cycle of central electricity generation. Greater gain will undoubtedly flow from applying H_2 to personal transport and domestic heating on a democratic, world scale. But that dream depends on accompanying changes in economic structures, social institutions and culture that will be difficult to achieve in the medium term.

Crucially, to tread the path to where H_2 could be substituted for C, would involve starting with the existing wealth and income inequalities. So long as fuel cells to produce work from H_2, H_2 itself and the means to generate H_2 at a domestic level come at a high cost to the consumer, only the rich will be able to substitute H_2 for C for heating their homes, propelling their cars and powering their laptops. The producer market will only do R&D and produce on such a scale as to bring costs of H_2 technology down, if there is mass demand, and, in turn, mass demand is only likely to be generated by a notable reduction in price that is stimulated by R&D and mass production – or else by political will (Bellaby, Flynn, & Ricci, 2005).

If science and engineering, rather than medicine, may be the key to reducing the huge and otherwise seemingly intractable health inequalities that prevail across the world and within each society, health policy must in future understand the science and technology and, more, the social and economic context in which it has to fit to be effective.

If the argument holds, national departments of health and the World Health Organization should turn their attention to the challenge posed by energy in the emerging world order, because it has enormous implications for public health generally and global health inequalities in particular.

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http://www.hydrogensociety.net/hydrogen *Safety Measures*

[1] The interdisciplinary work on which this paper is based owes a great deal to interaction with my colleagues in the EPSRC Supergen programme, especially the UK Sustainable Hydrogen Energy Consortium, which consists of both natural and social scientists. It also owes much to my colleagues in both public health research and sociology at Salford University. I would like to single out for special thanks my Salford colleague, the materials scientist, Keith Ross. Any errors are mine.

[2] H_2 is used as the symbol for hydrogen throughout, to denote a hydrogen molecule or mole, which is formed of two atoms.

[3] On December 2003, the European Union and 15 countries, including the UK and the USA, signed a pact to cooperate in the R&D for a hydrogen future. Some environmentalists have suggested that Bush's plans favour 'black' rather than 'green' hydrogen, that is, the generation of H_2 by fossil fuels. On the other hand, there were significant shifts to R&D on renewable energy in the 2003 US budget.

[4] Verne's novel is often cited for his early speculation about using hydrogen to power a submarine, but the first fuel-cell, which was powered by hydrogen, was developed by W.R.Grove in Wales in 1839.

[5] See the excellent presentations on http://www.e-sources.com/hydrogen, http://auto.howstuffworks.com/fuel-cell.htm

[6] An alternative use for H_2 in transport is to feed the gas into an internal combustion engine (ICE) and burn it in air. This is usually seen as an interim measure rather then a final recourse, for the ICE is less fuel-efficient than the fuel-cell (FC).

[7] Gauging the relative efficiency of H_2 demands a 'whole system' view of energy and work. Energy is conserved, whatever is done with it. As Scott points out, to speak of 'energy-intensive' production and 'consuming' energy is strictly speaking misleading. He prefers the neologism 'exergy' to 'energy', referring to work harvested from energy. It is often less than total energy, but sometimes more (as in heat pumps) (Scott, 2003).

[8] Several of the EPSRC UKSHEC work packages are dedicated to the key problem of storage for local, especially on-board vehicle applications.

[9] Generating hydrogen from biomass is the topic of a work package in the EPSRC UKSHEC. See also Iwasaki (2003).

[10] A journal published in the United States is - it seems - wholly dedicated to scientists who subscribe to the view that either global warming is a myth or it is real but benign for the environment and human health. It is *CO_2 Science Magazine*.

[11] There is much to do on this front. The rapid growth of air traffic has a major impact on global warming. Boeing and NASA are both engaged in development work on applications to aircraft. See Daggett (2003).

[12] As when planning permission was refused by Havering borough council for the Greater London Authority's plan to locate in Hornchurch an H_2 filling station for its H_2 powered bus project: *Financial Times* (London Edition) September 27, 2003. The author thanks John Mumford of BP, also a PhD student at University of Surrey, for his personal communication on this theme.

[13] For a review of these and other issues for current policy and investment in hydrogen technologies see DTI (2004) which is the final report of a technology assessment conducted by Eoin Lees Energy, E4tech and ElemenTenergy for the Department of Trade and Industry.

[14] See the literature on social capital and health, on the micro-level, Cooper, Arber & Fee (1999), and on the macro-level, Wilkinson (1999).