Is the "Hydrogen Economy" irrelevant, a distraction from development of climate change mitigation technologies?

During the A4 module a debate was staged on the rapidmovement to a Hydrogen Economy. It became apparent that there was a dearth of knowledge about the hydrogen economy within the participants. The author therefore decided to investigate whether, given the plethora of other climate change mitigation technologies around, the hydrogen economy is an irrelevance, or whether a hydrogen economy has a realistic chance of happening and through this learn more about the issues.

In an article in New Scientist in August 2004, two questions were posed:

> "Should developing a "hydrogen economy" be the number one priority for meeting our long-term energy needs while cutting greenhouse emissions? Or should we be investing in more immediate ways to cut emissions, such as burying the carbon dioxide produced by fossil fuels?" [New Scientist, August 2004]

They are positioned as a mutually exclusive scenario. This essay will look at whether the move toward a hydrogen economy is really a distraction from other alternative energy pathways.

Why the need for a hydrogen economy?

Since the 18th Century, when the Industrial Revolution began, the technology and transportation networks that support society have been powered by fossil fuels in the form of coal, oil, and natural gas. These fuels have stored the energy from the sun, converted by living things, over millennia, through natural processes such as photosynthesis. Through geological forces the remains of the living entities have been formed into convenient liquid, solid and gaseous fuels that (with minor refinement) give readily combustible fuels, and convenient release of energy. There is now a realisation that the use of these convenient power supplies has come at a previously hidden price – global climate change and threats to the environment. It took millions of years for the fossil fuels to be created, trapping carbon. This carbon has been released by burning over a geologically short period of time (150 years), releasing carbon dioxide so upsetting the natural carbon cycle and creating a "greenhouse effect" trapping heat in the atmosphere of the earth, raising the mean global temperature.

Beside this climate change, the other main driver for a change to a non fossil fuel economy, is fuel security.[DTI 2006a] The worlds' fossil fuel reserves are declining, (see figure 1), oil and gas production are approaching or have approached peak [Hirsch 2005]. Those that are known about are under the lands inhabited by people who do not totally agree with the foreign policies of the USA and her allies (e.g. the former Soviet Union, and EMEA) (see figure 2). To be dependent upon imports of fossil fuels from countries with which you may have disagreements in the future is seen as an unwise situation.

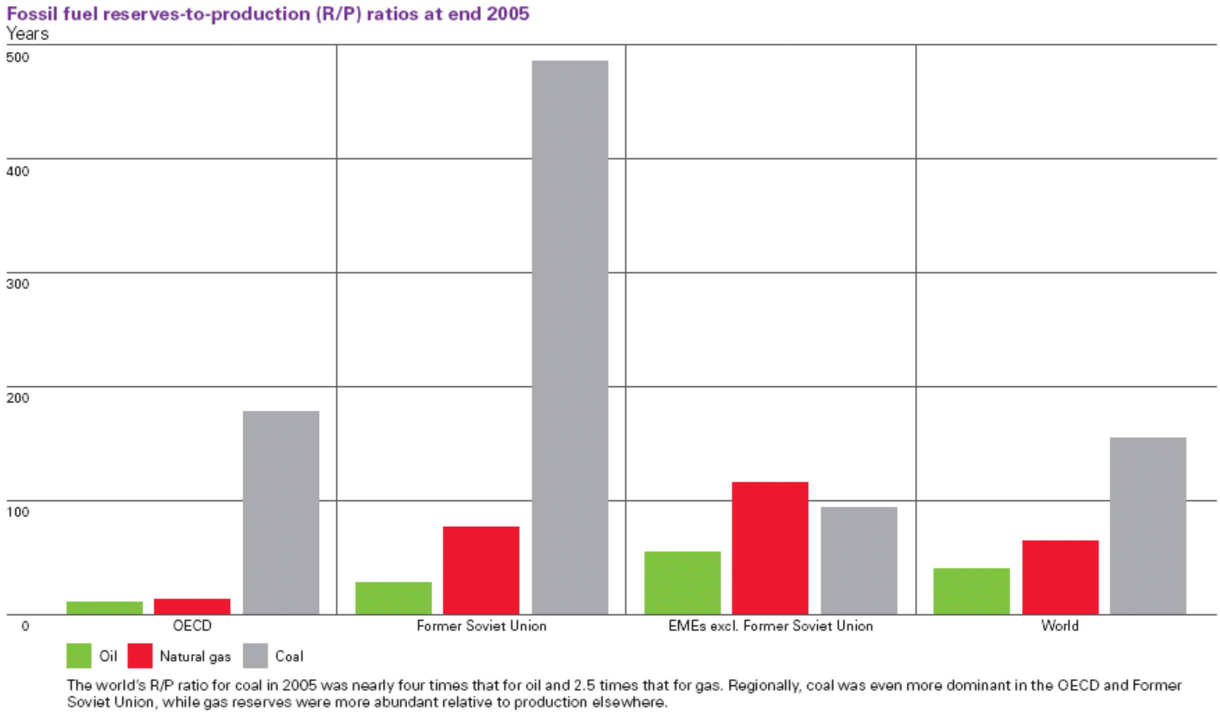


Figure 1 Source: BP - Statistical Review of World Energy June 2006 p43

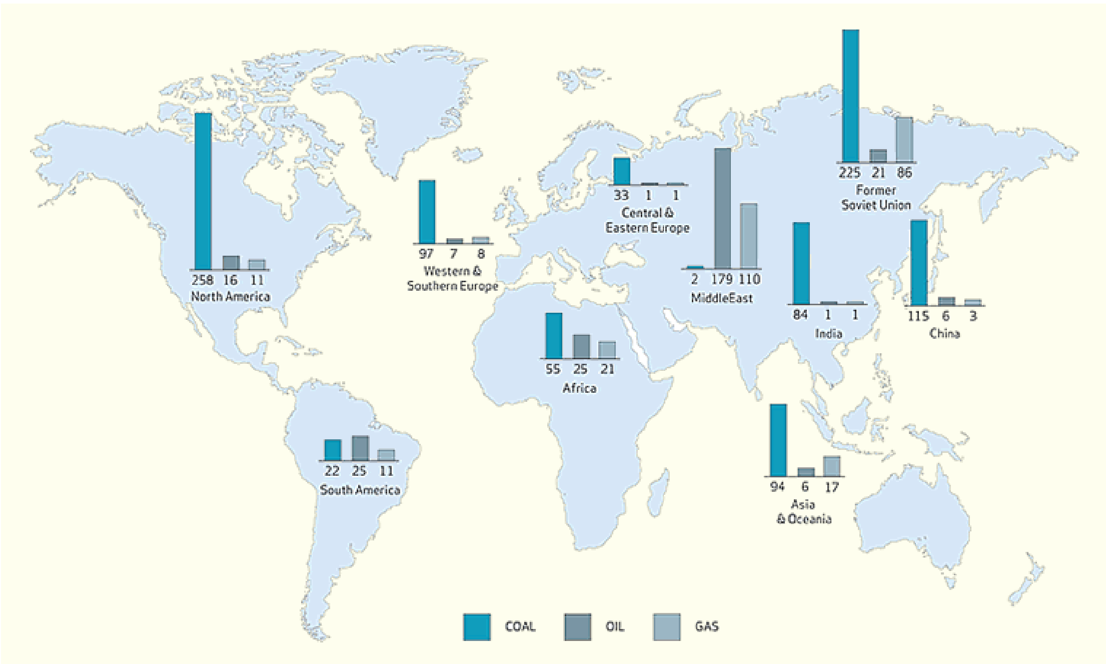


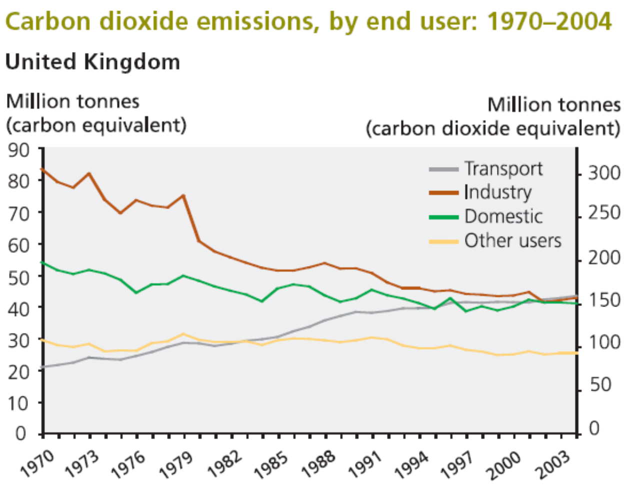
Figure 2
Location of the World's Main Fossil Fuel Reserves (Gigatons of coal equivalent)
Source: Optima, Vol.1 No.1, Feb. 2005; as published in ECOAL Newsletter July 2005, World Coal Institute

Greenpeace (2006) have concluded that
"Britain's dependence on foreignoil is set to grow eight-fold by 2030. Analysis by the Institute for European Environmental Policy (IEEP) predicts that under a business-as-usual model Britain will require 56 million tonnes of imported oil every year by 2030. Currently we import seven million tonnes annually."

Tony Blair, in May 2006, accepted that the UK reliance on foreign fuel sources is set to increase:
"We will move from 80 or 90% self-reliance on gas to 80 or 90% dependency on foreign imports, mostly from the Middle East, Africa and Russia"

So the search is on for an energy economy to replace the fossil fuel based economy of the industrial era and which will enable countries to maintain their own fuel sources and maintain economic growth.

The main focus of attention in the hydrogen economy has so far been on replacing gasoline in transport systems. A major reason for this emphasis is that, as Figure 3 shows, in the UK the emissions from transport have increased, whilst those from other sources have remained stable or declined.



	1970	1980	1990	2000	2004
				Million tonnes (carbon)	
Transport	21	28	38	41	43
Industry	83	60	52	43	43
Domestic	54	48	42	40	43
Other end users	29	29	29	25	25

Figure 3
Source : The environment in your pocket 2006 - Defra

(See Appendix 1 for a more detailed discussion).

There is more to the hydrogen economy than just fuel for automobiles. The hydrogen economy would encompass consumer electronics, using miniature fuel cells, and stationary heat generation. The hydrogen economy can be envisaged as facilitating (as a carrier and store of energy) a network of primary energy sources linked to multiple end uses as illustrated by Crabtree (2004) (Figure 4)

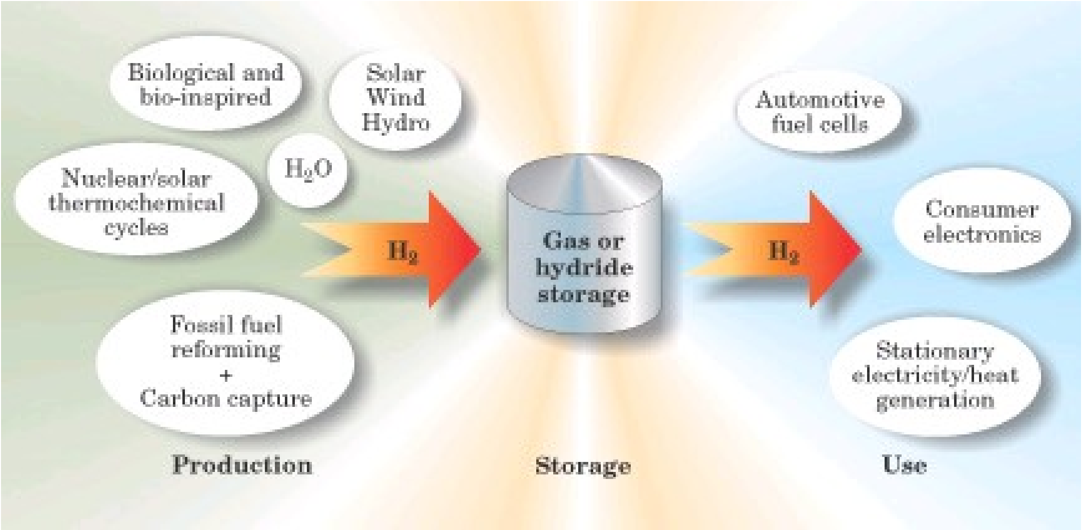


Figure 4 A Schematic of a Hydrogen Economy
Source : http://www.physicstoday.org Dec 2004

So why hydrogen ?

Despite making up 18% of the earths crust (by the number of atoms) hydrogen does not exist in its natural gaseous state in conveniently large quantities. Instead the vast majority is in chemical compounds with other elements. These compounds include water, natural gas, crude oil, coal and a few biological sources such as cellulose based biomass and sucrose. Unlike hydrocarbons which exist naturally as usable fuels, hydrogen has to be produced by releasing it by breaking the chemical bonds it makes with the other elements. Some of the energy used to release the gas can then be released by recombination (e.g. by combustion or in a fuel cell). Hydrogen is an energy carrier not an energy source.

Renewable energy sources such as wind, wave and solar all suffer the problem of being intermittent sources of energy. The wind does not always blow; wave power depends on weather systems; the sun does not shine at night and is affected by cloud cover. Hydrogen can be used as both an energy carrier and a storage medium to compensate for this intermittency. Hydrogen is therefore seen as a way forward for facilitating the introduction of renewable sources, serving both the electricity and the transportation sectors [Clark & Rifkin 2006]. There are problems with the production and distribution of hydrogen. There is the inefficiency in energy terms in having to produce hydrogen[1], the difficulty in handling a reactive element that is a gas under normal atmospheric conditions, and the effect of by-product CO2. Van Ruijven et al (2006) concluded that climate policy, limiting CO2 emissions, would appear to be a prerequisite in the planning of a hydrogen economy. (see Appendix 2).

The primary end-user technology associated with hydrogen is the fuel cell. The main advantage of fuel cells is in vehicular applications, as they "double the efficiency of transport compared to current internal combustion engines" [van Ruijven et al, 2006]. Randle (2007) quotes fuel cell efficiency at 50-70% compared to 15-17% efficiency for gasoline (fuel to output shaft).

Is anything happening in Europe and the UK towards a hydrogen economy or is it all US hype?

[1] Any conversion from one form of energy to another consumes more useful energy than it yields. [Lovins 2005]

There have been many recent developments in the UK and in Europe driven by the need for reduced carbon emissions and the need to secure fuel supplies. The developments are in the early stages, but the policy and infrastructure for the guidance and development of R&D aims has been at the forefront of government thinking.

In Europe, in 2003, President Prodi stated that the EU could either "sink or swim" in competing for hydrogen markets. The European Community has allocated billions of Euros to funding research, deployment and procurement of hydrogen based commercial products and services.[Clark & Rifkin 2006].

The High Level Group on Hydrogen and Fuel cells (HLG) was formally launched in Brussels in October 2002. Its aim was "to formulate a collective vision on the contribution that hydrogen and fuel cells could make to the realisation of sustainable energy systems in future". It presented a summary report[2] "The hydrogen economy - a bridge to sustainable energy" in Brussels, June 2003.

There is political momentum building up in Europe for a move towards a hydrogen economy with a timeline of "20 years for commercial applications to become the norm and 40 years for the completion of the transition that we are seeking"[3]. The EU president has stated the goal of "of achieving a step-by-step shift towards a fully integrated hydrogen economy, based on renewable energy sources, by the middle of the century." He also announced the formation of a "European Hydrogen and Fuel Cells Partnership" to foster a political environment conducive to a "government-business-civil society partnership to facilitate the switchover to renewable sources"

At the same conference the intentions of the Mayor of London to '…strongly support the development of hydrogen and fuel cell technologies in London as a means of providing low and zero emission energy' through the London Hydrogen Action Plan were outlined [Jones 2003].

In the UK progress towards the infrastructure for a sustainable energy policy has been made. The coordination of effort of different government departments was addressed in June 2003 with the launch of the "Sustainable Energy Policy Network"[4] by the Secretary of State for Trade and Industry with the aims of bringing together relevant "Government players, Ministerial and official". This should remove the duplication of effort and streamline decision making.

The UK Government commissioned a report in 2004 by E4tech, Element Energy and Eoin Lees Energy, resulting in the "Strategic Framework for Hydrogen Energy in the UK" [e4tech 2004]. This suggested that by 2030, in the UK, "hydrogen energy could provide competitive CO2 reductions … using fuel cell vehicles". As a result UK Government set up the "Low Carbon Vehicle and Fuel Cell Technologies Centre of Excellence" based in Loughborough (www.lowcvp.org.uk) in December 2004 at a cost of £7.5m.

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[2] http://cordis.europa.eu/sustdev/energy/h2_pres.htm

[3] In the speech Research Commissioner Phillipe Busquin outlined that: "In the short and medium term - and by that I mean decades - hydrogen will naturally be produced largely from fossil fuels or nuclear energy in those countries which retain that option." However in the same speech he stated that the EU are working to create a hydrogen economy based on renewable energy sources.

[4] http://www.dti.gov.uk/energy/policy-strategy/sepn/index.html

A consortium of academic and industry researchers, has been created under the EPSRC[5] **"**Supergen**"** programme to consider the infrastructure necessary to support a hydrogen economy. The" Supergen UK Sustainable Hydrogen Energy Consortium (UK-SHEC)" [6] is currently researching the production, storage, distribution and use of sustainable hydrogen as an energy carrier. This work is led by the Universities of Oxford and Bath (funding £3.5 million over 4 years). Fuel Cells funding from Supergen was £2.1m over 4 years led by Imperial College London and University of Newcastle upon Tyne.By comparison in the SUPERGEN initiative on Biomass got £2.9m over 4 years, and Photovoltaics £3.1m over 4 years. It can be seen that the funding for hydrogen has not been totally at the exclusion of other projects but on a par with them.

On March 7 2006 the Science Budget allocations included an increase in funding for energy R&D "from £40m to £70m per year plus additional support for business via the DTI Technology program and The Carbon Trust".[DTI 2006]. The Government has also launched "a funding package or £40m over 4 years for demonstrations across carbon abatement, hydrogen and fuel cell technologies with £15m expected to be dedicated to hydrogen and fuel cell project split 50/50" [DTI 2006].

An "Energy Review" was undertaken by the UK Government in 2006[7] resulting in a report "The Energy Challenge"[8] [DTI 2006a] in which the framework for the energy policy for the decades ahead was set out. This expected hydrogen to make a major contribution to reducing transport emissions post 2020.

The Campaign for a Hydrogen Economy (CHEC) was formed in 2003 (see Appendix 4). As of Feb 2007 when the author contacted themthey have not really made much of an impact nationally.

A **UK Hydrogen Association** (www.ukha.org) exists which according to their website "was created to span sector boundaries, provide a strong national voice on hydrogen energy, engage government, and drive the UK hydrogen economy"

Hydrogen is seen, within government funding policy, as the link between the other forms of clean energy production and has been bound in with them as the Energy Policy has been developed. Supporters of biomass, PV et al could of course claim that hydrogen has "distracted" funds away as there is another R&D mouth to feed.

It is not only the government that is making progress. An example of how the **UK energy industry** is proceeding with a hydrogen generation project can be found in the BP partnership with Scottish & Southern Energy in Peterhead, Scotland. (see appendix 3). www.peterheadhydrogenpower.com .

Conclusions:

There is such a quantity of work going on that this essay can only be a brief introduction to the state of play. There are swathes of argument on the practicalities of the hydrogen economy, each of which have filled numerous papers, with few firm conclusions yet, and which cannot be coveredin this essay. The study area is relatively new, with projected timescales to realisation of a hydrogen economy of 20-40 years,

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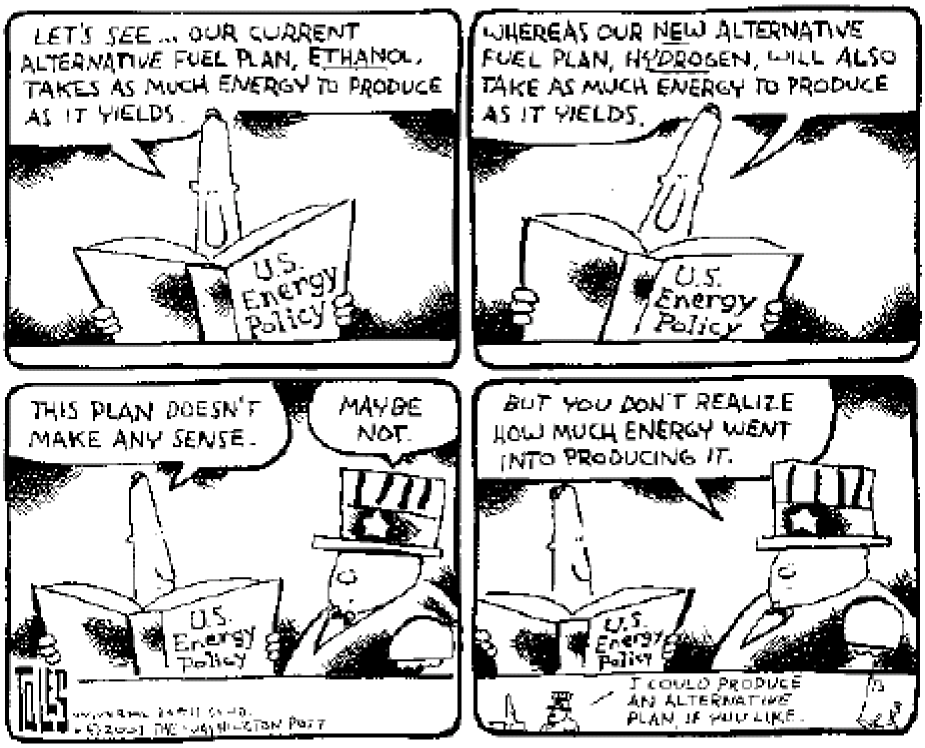
[5] Engineering and Physical Sciences Research Council
[6] http://www.epsrc.ac.uk/ResearchFunding/Programmes/Energy/Funding/SUPERGEN/SustainableHydrogenEnergy.htm
[7] http://www.dti.gov.uk/energy/review/page31995.html
[8] http://www.dti.gov.uk/files/file31890.pdf

and there are few books written about it. Those that exist are not available from the university libraries in Preston and Lancaster.

The purpose of this essay was to look at whether a hydrogen economy has a realistic chance of happening, or whether it is just an irrelevant distraction. It has proved to be no irrelevance, but firmly on the policy roadmap of the UK Government as can be seen from the energy policy statements, and the funding priorities through the different funding schemes. This is being driven by commitments to policy changes instigated by the European Union. Whether it proves a distraction only time will tell, but there is now so much political capital riding on the hydrogen economy in Europe that it is will have a good probability of succeeding. .



Source http://planetforlife.com/h2/h2politics.html

There are challenges to the traditional/orthodox “green” way of thinking:

- The capacity of clean renewable generation to create a surplus of electricity which can be used for hydrogen generation, as envisaged, is some way off. For the next few decades the use of nuclear power to produce the electricity needed for the electrolysis of water to create hydrogen, is firmly in the frame, despite the protests of the green movement and the pro-hydrogen lobby.

- The hydrogen economy will be less energy efficient than the carbon economy due to the need to put primary energy in to get “secondary” hydrogen out, but that, whilst being a challenge to the “more efficient is better” mantra, may be a trade off we have to make in order to reduce CO2 and prevent a global catastrophe. This may be offset by improvements in technology such as the fuel cell.

- A Hydrogen economy without increased development of carbon capture and sequestration (CCS) does not make environmental and economic sense. Only when CCS is well enough developed and/or renewable energy is available in sufficient quantity to supply a surplus, available for the production of hydrogen, will a hydrogen economy realise its true potential benefits.

- Politicians are setting out the framework to control developments. They also control a major part of the R&D funding. The future of the Hydrogen Economy is no longer under the control of environmental technologists.

The hydrogen economy is far from a finished as a concept, and cannot exist in isolation.Hydrogen is an energy enabler, an energy carrier, not a primary energy provider. There is a great deal of research and development work that has to be undertaken into primary renewable generation, carbon sequestration technologies, and material science, and the integration of the elements, before a hydrogen economy can become an economic reality.

There is another challenge here for orthodox “environmental” thinking where the various technologies for “stationary”energy generation are often seen in isolation from mobile applications. An economy looks at the whole process, not only of generation but of delivery and use. Hydrogen currently seems the best option to give that linkage.

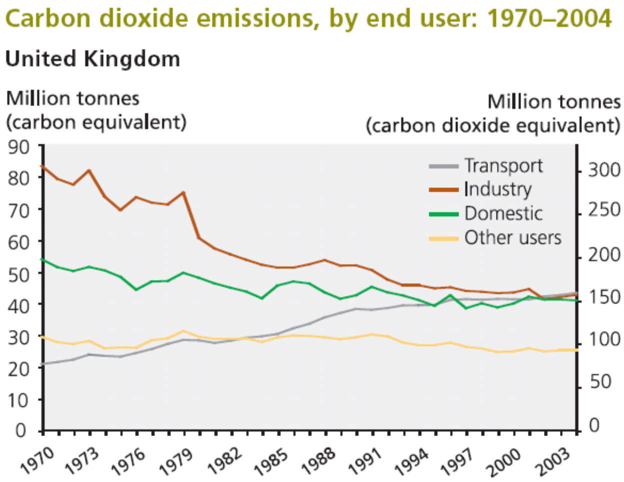
Far from being a question of a hydrogen economy distracting from other climate change reduction technologies, the hydrogen economy can and should serve as a focal point directing effort in the other technological areas and providing a linkage between them, facilitating the move away from a fossil fuel economy within the UK.

Appendix 1

Isn't this really all about cars?

The bulk of research into the hydrogen economy, such as that by Lovins , Bossel and Crabtree seems to be centred on the transport sector. To understand this we must look at the distribution of causes of carbon emissions.

Figure 5 shows the trends in emission of carbon dioxide by end user for the United Kingdom. From here can be seen that the emissions from transport have increased, whilst those from other sources have remained stable or declined.



Million tonnes (carbon)

	1970	1980	1990	2000	2004
Transport	21	28	38	41	43
Industry	83	60	52	43	43
Domestic	54	48	42	40	43
Other end users	29	29	29	25	25

Figure 5
Source : The environment in your pocket 2006 - Defra

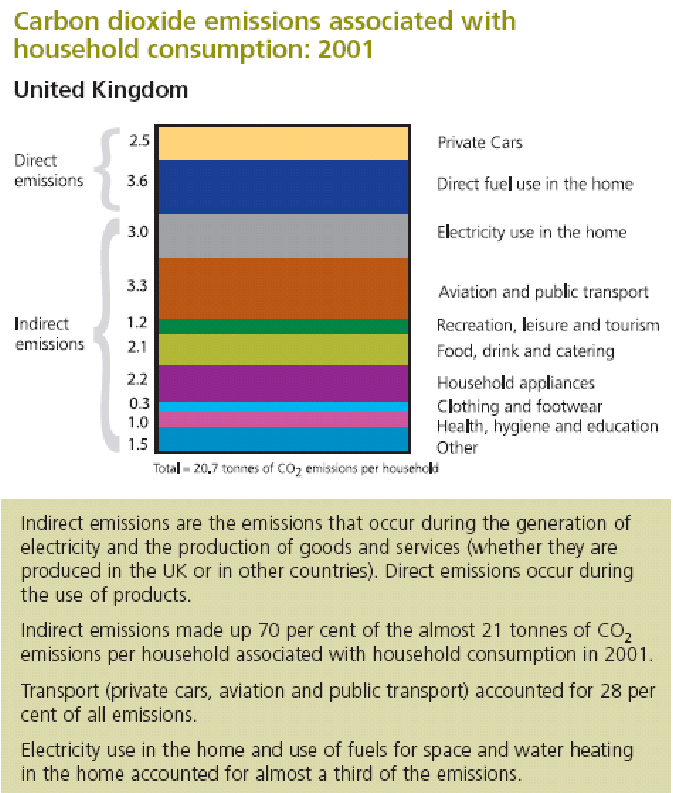


Figure 6
Source : The environment in your pocket 2006 - Defra

Figure 6 shows that private car emissions make up over 12% of household emissions.

There is little chance, at least in the short term, of reversing the love affair of the motorist and his automobile.

> "I have to say there are a growing number of skeptics who believe that the automobile genie is out of the bottle, forget it, you will never stuff it back in. These people cannot be discounted and they come from Harvard, John Cain, John Myer…" [Soberman, 2002].

The new energy economy in the UK must therefore address the issue of rising greenhouse gas (GHG) emissions from transport if it is to be successful, whilst addressing the emissions from the other sectors.[9] Research on hydrogen fuelled cars is ongoing. The focus is split between burning hydrogen as a fuel in internal combustion

[9] It is technologically difficult to remove the carbon dioxide from the exhaust gases of any flue "because CO2 is dilute (3-15 vol%), at low pressure (15-25 psi), and often contaminated with traces of sulphur and particulate matter" [NETL 2006]. Each automobile on the road has its own flue (the exhaust pipe), so the problem is multiplied by about 600 million [http://en.wikipedia.org/wiki/Car_culture]. Therefore, ideally, the sequestration of carbon needs to be performed at a more centralised location. This leads to a concentration on alternative automotive fuels, which produce zero CO2 emissions at the point of combustion. Hydrogen has been proposed as an alternative.

engines and using fuel cells[10] with the added distraction of hybrid cars and methanol as alternatives [Lovins, Wilson].

> "Most authors therefore project the most significant break-through of hydrogen (if any) in the future transport sector (even without electricity delivery)
> [Van Ruijven etc al, 2006]

For stationary power generation, where equipment bulk is not such a problem, other technologies such as biomass, solar, wind, Combined Heat and Power (CHP) are already well developed. It is in the compact, mobile applications that they are not seen as feasible.

Appendix 2

a) Production problems with hydrogen

There are currently two main ways of releasing hydrogen:

- Electrolysis of water
- Using temperature, pressure and a catalyst to force a chemical reformation of hydrocarbons.

Both of these require significant input of energy to achieve. Bossel (2006) calculated that for the electrolysis of water there is a 30% energy loss, and for reforming of natural gas 10% energy loss. He then estimates an additional 100% of the energy stored in the hydrogen will be used for transportation to the customer.

Boyle (2004) also mentions two other methods which are not currently used in wide scale production:

- Gasification of biomass
- Photoelectrochemical cells producing hydrogen from water via artificial chemical photosynthesis.

Currently reformation of hydrocarbons is the significantly cheaper option. [Eliasson & Bossel 2003]. However in the reformation of methane (or any hydrocarbon) a by-product is CO2. This is what leads Joseph Romm[11] to call this process "dirty hydrogen" because it will be made from natural gas as this is currently the cheapest way to make hydrogen. [New Scientist 2004] He claims that "the focus on hydrogen is damaging the chances of solving the climate change.

So what is needed to avoid the "dirty hydrogen" scenario which will just make the climate problem worse. Bas van Ruijven [2006] modelled the effect that the introduction of hydrogen into global energy systems would have on CO2 emissions with and without climate policy enforcements. Two of the conclusions were:

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[10] "The main advantage of fuel cells is in vehicular applications, as they double the efficiency of transport compared to current internal combustion engines" [van Ruijven et al, 2006]. Randle (2007) quotes fuel cell efficiency at 50-70% compared to 15-17% efficiency for gasoline (fuel to output shaft).

[11] Romm worked for Lovins at the RMI and then was responsible for overseeing Department of Energy's Office of Energy Efficiency and Renewable Energy during the Clinton Administration

"Hydrogen will probably not play an important role before mid-21st century in the world energy system, neither with nor without climate policy."

and

"Without Climate Policy, CO2 emissions from energy systems with hydrogen are likely to be higher than those of systems without hydrogen. The reason for this is that hydrogen is produced at the lowest cost from coal – hence coal will be a substitute for oil in the primary energy supply." [Bas van Ruijven et al, 2006]

b) Distribution problems with hydrogen

Hydrogen as a gas has a very small energy density 10MJ/m^3 which is about a quarter that of natural gas (Boyle 2004). This makes for problems with storage and distribution. For example it means that it would take more energy to pump the same amount of energy as hydrogen than as natural gas.There is also the problem of the reactivity of hydrogen which causes it to react with steel and organic compounds, making steel pipes brittle, corroding valves and taps,and require alternative expensive lubricants if pumped through existing natural gas pipelines (a problem dismissed too casually by Lovins (Myth #4))

Hydrogen can be stored in several ways:

- as compressed gas – pressurised to around 300 atmospheres
- as liquid hydrogen – requiring cooling to -253 C and the use of highly insulated storage
- adsorption or absorption[12] of hydrogen into various metals and alloys forming physical metal hydrides. The hydrogen can be liberated by heating them.
- Reaction with alkali metals to form chemical metal hydrides which can be broken down by heating.

Bossel (2004) analysed the energy consumption for different hydrogen delivery paths (figure 7). He only assumed distribution by road tanker, not by pipeline.

He came to the conclusion that none of the distribution pathways would be attractive and that "elemental hydrogen would not become important in a future energy economy". This is disputed by Lovins who puts forward a transitional strategy to overcome the problems of delivery based on decentralised natural gas reforming.

[12] Adsorption - to gather (a gas, liquid, or dissolved substance) on a surface in a condensed layer
Absoprtion – taking up within the lattice structure of the molecule.

	Energy cost in HHV of H_2	Factor	Path A gas	Path B liquid	Path C onsite	Path D hydride
Production of H_2						
Electrolysis	33%	1.33	1.33	1.33		1.17*
Onsite production	65%	1.65			1.65	
Packaging						
Compression 20 MPa	8%	1.08	1.08			
Liquefaction	40%	1.40		1.40		
Chemical hydrides	60%	1.60				1.60
Distribution						
Road, 20 MPa H_2, 100 km	6%	1.06	1.06			
Road, liquid H_2, 100 km	1%	1.01		1.01		
Storage						
Liquid H_2, 10 days	guess: 5%	1.05		1.05		
Transfer						
10 MPa to 40 MPa	3%	1.03	1.03		1.03	
Delivered to User						
Energy Input/HHV of H_2			1.59	2.02	1.59	1.90**

* Only 50% of the hydrogen released comes from electrolysis

** Excluding energy needed to produce alkali metals

Figure 7 Energy consumption for different hydrogen delivery paths
Source Bossel 2004

Delivery Paths assumed by Bossel Figure 7

A produced by electrolysis, compressed to 20 MPa and distributed by road to filling stations or consumers, stored at 10 MPa, then compressed to 40 MPa for rapid transfer to vehicles at 35 MPa.

B produced by electrolysis, liquefied and distributed by road to filling stations or consumers, then transferred to vehicles.

C produced by electrolysis on-site at filling stations or consumers, stored at 10 MPa, then compressed to 40 MPa for rapid transfer to vehicles at 35 MPa.

D produced by electrolysis and used to make alkali metal hydrides.

One fundamental infrastructure problem in the UK for any electric or hydrogen fuel cell based car is the reliance by the UK motorist on on-street parking some distance from the owners' house. The current ideas appear based around sub-urban USA where automobiles are garages or parked close to the dwelling. Many UK dwellings do not have garages. The obstruction of pavements by extended charging leads and the probability of vandalism and theft have not been addressed.

Appendix 3

The Peterhead Hydgrogen Generation scheme

BP, in partnership with Scottish & Southern Energy are currently undertaking a $600 million project to create the world's first industrial scale hydrogen power project in Peterhead, Scotland.

The project's hydrogen reformer and power station will be located adjacent to Scottish & Southern Energy's Peterhead power station in Aberdeenshire.

The aim is to reform 70 million cubic feet of natural gas to produce into hydrogen, and capture the carbon (1.8 million tonnes CO2 a year) by transporting it by existing pipeline, 240km to the Miller oilfield where it will be "injected more than 4km under the seabed and stored in underground oil reservoirs where it will be used to flush out extra oil". It is believed that this will extend the life of the Miller field by 15-20 years producing an extra 50-60 million barrels of oil. The hydrogen created will be used to fuel the generation of 350-475 MW of "low-carbon" electricity. It is hoped that the project will be commercially operational in 2010.

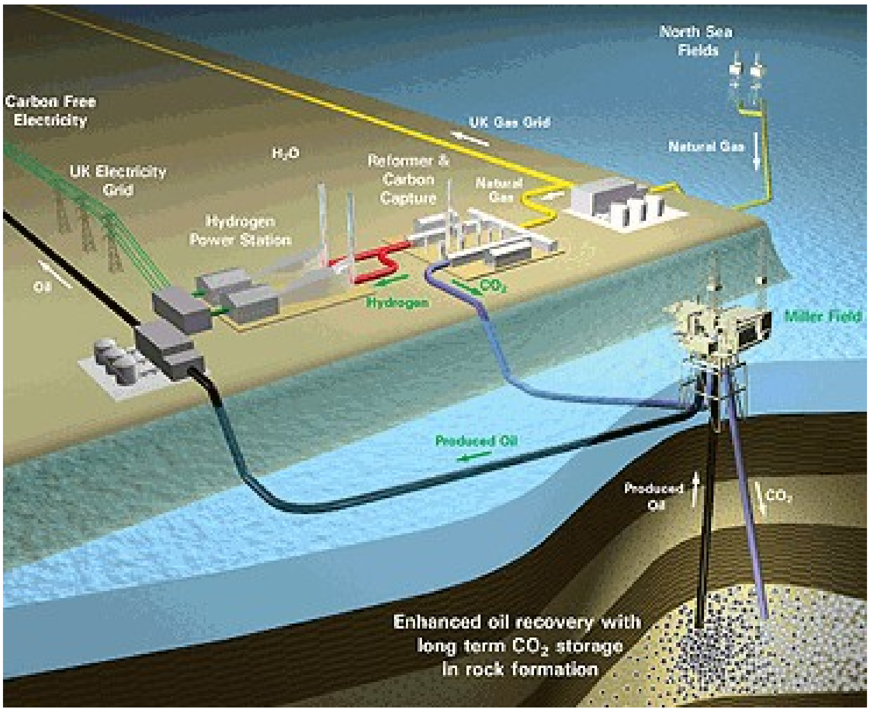

Figure 8 Peterhead Hydrogen Generation with CCS scheme
http://www.peterheadhydrogenpower.com/go/doc/1141/119911

Appendix 4

The **"Campaign for a Hydrogen Economy"** was formed in 2003

Its aims are:

- To work for the widespread recognition of renewably produced hydrogen as the fuel of choice for all human needs.
- To work, in concert with similar organisations worldwide, for the rapid and full displacement of fossil fuels by renewably produced hydrogen.
- To ensure that the legal and human rights of nations, tribal peoples and individuals are held in full respect whilst the fossil fuel industry and its infrastructure are wound down, and the alternative hydrogen economy is established.

Source : www.hydrogeneconomy.org.uk

It "promotes public awareness of the use of hydrogen as a form of renewably – generated fuel".. Their aim is the elimination of carbon emissions – reduction is no longer an adequate aim (CHEC 2006 point 5.1). They reject the use of fossil fuels as source for reforming. They therefore favour only the manufacture of hydrogen by electrolysis using renewable energy source (solar, wind and wave – NOT nuclear).

They suggest using solar voltaics in the Sahara transmitting high voltage direct current over 2000km from North Africa, under the Mediterranean, through Europe to the UK. They do recognise that the political barrier due to "past and present tensions" makes this idea "simply unthinkable" [CHEC 2006 4.2.2.1] but recommend it anyway [CHEC 2006 5.2]. This does not appear to offer much in the way of fuel security.

Their submission to the DTI energy review depends on "advances in material science" and "opportunities for fair trade … and real debt relief: providing the energy exported from the Sahara in the form of solar electricity and solar hydrogen".

They recognise the difficulties of transportation, storage and dispensing of hydrogen examined in details by others such as Lovins, Wilson, Crabtree and Bossel, but have faith in R&D to overcome what others see as significant obstacles.

> "It is thus incumbent on the research community … to increase the transmissibility of hydrogen, and thus to ease our passage into the full hydrogen economy" [CHEC 2006]

References

Bas van Ruijven et al., 2006, *"The potential role of hydrogen in energy systems with and without climate policy"*, International Journal of Hydrogen Energy (2006), doi: 10.1016/j.ijhydene.2006.08.036, accessed from the internet (www.sciencedirect.com) 5th Feb 2007

Bossel 2006, *"On the way to a sustainable energy future",* Seminar presentation to European Fuel Cell Forum, November 20 2006 downloaded from http://www.efcf.com/reports/E17.pdf accessed from the internet 6th Feb 2007

Bossel et al, 2004 , *"The Future of the Hydrogen Economy: Bright or Bleak?"*, 2003 Fuel Cell Seminar revised 28th October 2004 http://planetforlife.com/pdffiles/h2report.pdf accessed from the internet 6th Feb 2007

Boyle G et al (2004) *"Renewable Energy: power for a sustainable future"*, Milton Keynes, Open University & Oxford, Oxford University Press.

CHEC, 2006, *"Department of Trade and Industry: Energy Review Consultation 2006 submission by The Campaign for a Hydrogen Economy"*, The Campaign for a Hydrogen Economy, April 2006 (obtained by mail 9th Feb 2007)

Clark & Rifkin, 2006, *"A green hydrogen economy"* Woodrow W Clark II, Jeremy Rifkin, Energy Policy 34 (2006) 2630-2639 http://www.elsevier/locate/enpol accessed Feb 01 2007. accessed from the internet 8th Feb 2007

CNN 2002, *"9/11 study: Air traffic affects climate"*
http://archives.cnn.com/2002/TECH/science/08/07/contrails.climate/
accessed from the internet 1st Feb 2007

Crabtree etc al, 2004, *"The Hydrogen Economy"*, George W Crabtree, Mildred S Dresselhaus and Michelle V Buchanana, Physics Today Dec 2004, http://www.aip.org/pt/vol-57/iss-12/p39.html accessed from the internet 1st Feb 2007

DTI 2006, *"Hydrogen Energy Strategic Framework For The UK - The Government's Response"*,Department of Trade & Industry, 2006 accessed from website, www.dti.gov.uk/files/file26736.pdf accessed from the internet 6th Feb 2007

DTI 2006a, "The Energy Challenge", HM Government, July 2006, http://www.dti.gov.uk/files/file31890.pdf accessed from the internet 6th Feb 2007

E4tech 2004, *"A Strategic framework for Hydrogen energy in the UK – Final Report December 2004"*, e4Tech, Element Energy, Eoin Lees Energy, downloaded from http://www.dti.gov.uk/files/file26737.pdf accessed from the internet 6th Feb 2007

Greenpeace, 2006
http://www.greenpeace.org.uk/contentlookup.cfm?ucidparam=20061207113448 accessed from the internet 28th Feb 2007

Hart 2005, *"A Strategic framework for Hydrogen energy in the UK"* Presentation by David Hart, E4tech to H2Net Summer Meeting June 2005
http://www.h2net.org.uk/PDFs/AnnualMeeting_2005/h2net_summer05_s2_Hart.pdf
accessed from the internet 6th Feb 2007

Hirsch 2005*, "Peaking Of World Oil Production: Impacts, Mitigation, & Risk Management"*,Robert L. Hirsch, SAIC, Project Leader Roger Bezdek, MISI Robert Wendling, MISI, February 2005. www.netl.doe.gov/publications/others/pdf/Oil_Peaking_NETL.pdf
accessed from the internet 28th Feb 2007

Jenny Jones 2003, *"A Hydrogen Economy for London"* presentation by Jenny Jones, Chair of the London Hydrogen Partnership,London Deputy Mayor, UK "The hydrogen economy – A bridge to sustainable energy Brussels, 17 June 2003"
Accessed from
ftp://ftp.cordis.europa.eu/pub/sustdev/docs/energy/sustdev_h2_sessionb_jones.pdf
accessed from the internet 26th Feb 2007

LBST 2003, *"Comments on the Paper by Baldur Eliasson and Ulf Bossel 'The Future of the Hydrogen Economy: Bright or Bleak ?"*, L-B-Systemtechnik GmbH, www.lbst.de July 2003 accessed from the internet 6th Feb 2007

Lovins, Amory, 2005*, "Twenty Hydrogen Myths – corrected and updated 17th Feb 2005"*, Rocky Mountain Institute. www.rmi.org accessed from the internet 5th Feb 2007

NETL, 2006, *"Carbon Sequestration Technology Roadmap and Program Plan 2006",* US Department of Energy, Office of Fossil Energy, National Energy Technology Laboratory. http://www.fossil.energy.gov/sequestration/publications/programplans/2006/2006_sequestration_roadmap.pdf accessed from the internet 28th Feb 2007

Peterhead Project – BP http://www.bridgecomms.co.uk/bp/df1.swf accessed from the internet 1st March 2007

Philippe Busquin 2003, *"The hydrogen economy – A bridge to sustainable energy Brussels, 17 June 2003 Closing speech by Philippe Busquin Member of the Commission responsible for research."* ftp://ftp.cordis.europa.eu/pub/sustdev/docs/energy/sustdev_h2_conclusions_busquin_en.pdf accessed from the internet 1st March 2007

Randle, Damian 2007, *"Lecture: Hydrogen & Fuel Cells",* Module A4 Centre for Alternative Technology MSc Architecture: Advanced Environmental and Energy Studies, Jan 2007

Richard Soberman, Professor Emeritus, University of Toronto, *"Cities and Transportation: Choices and Consequences Conference ",* Tuesday, February 19, 2002, http://www.sfu.ca/dialog/cities/session5.htm accessed from the internet 3rd March 2007

Romano Prodi, "*Keynote speech to Conference on the Hydrogen Economy, Brussels, 16 June 2003"* ftp://ftp.cordis.europa.eu/pub/sustdev/docs/energy/sustdev_h2_keynote_prodi.pdf accessed from the internet 1st March 2007

Tony Blair 2006, "*Speech to the CBI annual dinner May 2006*" quoted on BBC Website. http://news.bbc.co.uk/1/hi/uk_politics/4987196.stm. accessed from the internet 1st March 2007

Wilson, John R 2003 "The Truth about Hydrogen (a response to Amory Lovin's 'Twenty Hydrogen Myths'", September 25, 2003 Version 4.0, The Management Group, June 2003 http://www.mnforsustain.org/energy_truth_about_hydrogen_wilson.htm accessed from the internet 5th Feb 2007