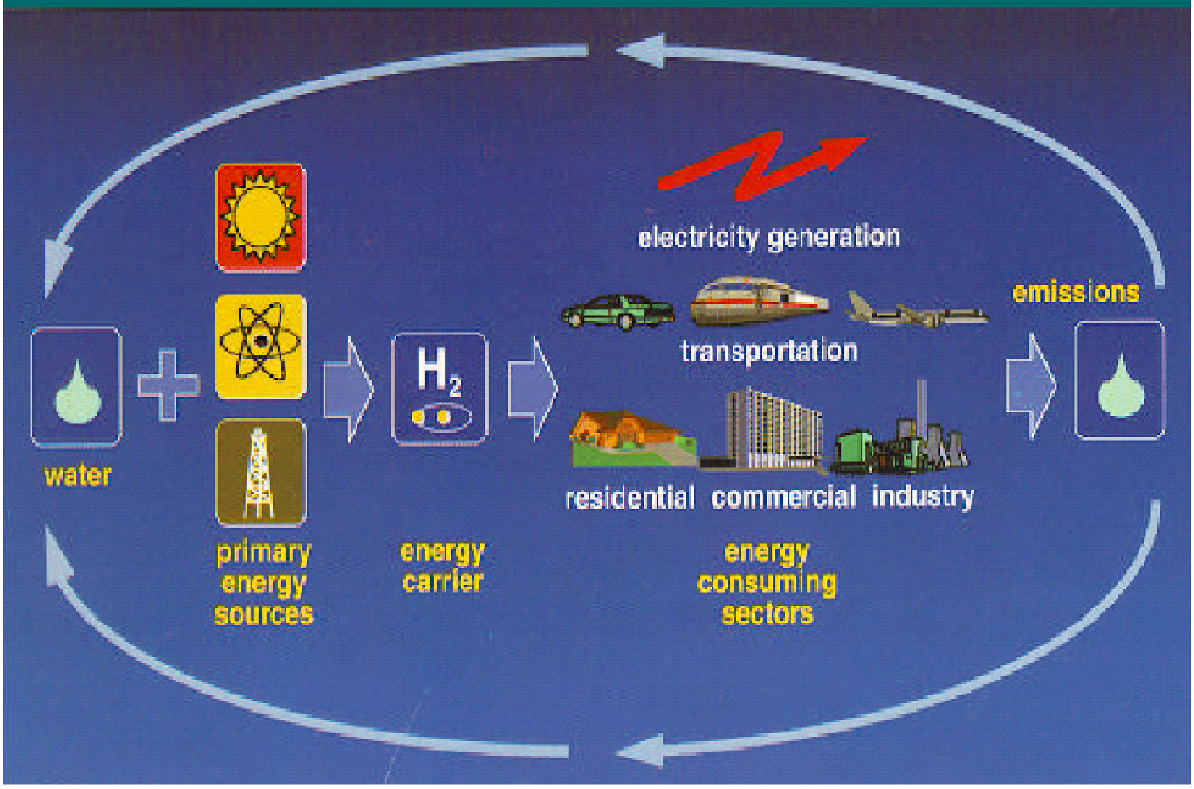
The Hydrogen Economy

Hydrogen and Fuel Cells

Ed 1 – 2006

"I believe that one day hydrogen and oxygen, of which water is constituted, will ….represent an inexhaustible source of warmth and light" - Jules Verne, Mysterious Island (1874)



Courtesy: Air Products and Chemicals Inc

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Introduction

- What is the Hydrogen Economy? Is it going to happen?
- The energy sector of the world is on the cusp of immense change
- The world's demand for energy is voracious and increasing
- Our energy infrastructure is aging and large chunks are at the end of their design life
- People are becoming aware that the primary energy resource, fossil fuels, is not limitless
- We are constantly bombarded with catastrophic predictions of global warming
- So what is the answer?
- One solution being put forward is to convert from the Carbon Economy which fuelled the Industrial Revolution to a Hydrogen Economy
- But what is this and will it solve the problems?

Report Scope

- This report explains what a Hydrogen Economy would be
- It describes the many obstacles which would need to be overcome to bring it into existence
- The development of the Hydrogen Economy will advance on two parallel fronts
- The development of another technology, the Fuel Cell, is essential to the exploitation of Hydrogen; the two are interlinked
- Fuel cells utilise the chemical energy of hydrogen to produce electricity and thermal energy
- We are further along the road than many people realise, the report outlines the development of Fuel Cells as technologies and markets
- The technology and infrastructure to produce and deliver large quantities of hydrogen to consumption points must be created
- The many and varied technologies of Fuel Cells, alternatives to batteries and the combustion engine, must be developed and refined to exploit the properties of hydrogen
- Hydrogen will be produced from a diverse base of primary energy feedstocks, or from water using renewable electricity in the process
- Fuel Cells are already being commercialised and are used in a wide variety of products

Key Research Findings

- Hydrogen and Fuel Cells have competitors
- New technologies include large scale electrification in conjunction with plug-in hybrid vehicles and Li-ion batteries in transport
- In the stationary applications market, distributed electricity generation or cogeneration present an alternative to hydrogen
- Other significant competitors are a new level of power generation technologies, such as large, increased efficiency coal and gas-fired power plants, possibly using underground coal gasification (UCG) with CO2 capture and storage (CCS), renewable electricity supply technologies which are already widespread in the market (wind and solar PV) or now being commercialised (ocean and tidal energy), and new nuclear power technologies
- ABS believes that in 50 years the world may use a hybrid, a composite of Hydrogen and Fuel Cells, beside other energy carriers, distributed generation, gas and electricity, renewable energy and emission-free generation from hydrocarbons using underground coal gasification, carbon capture and storage
- The possibilities are endless

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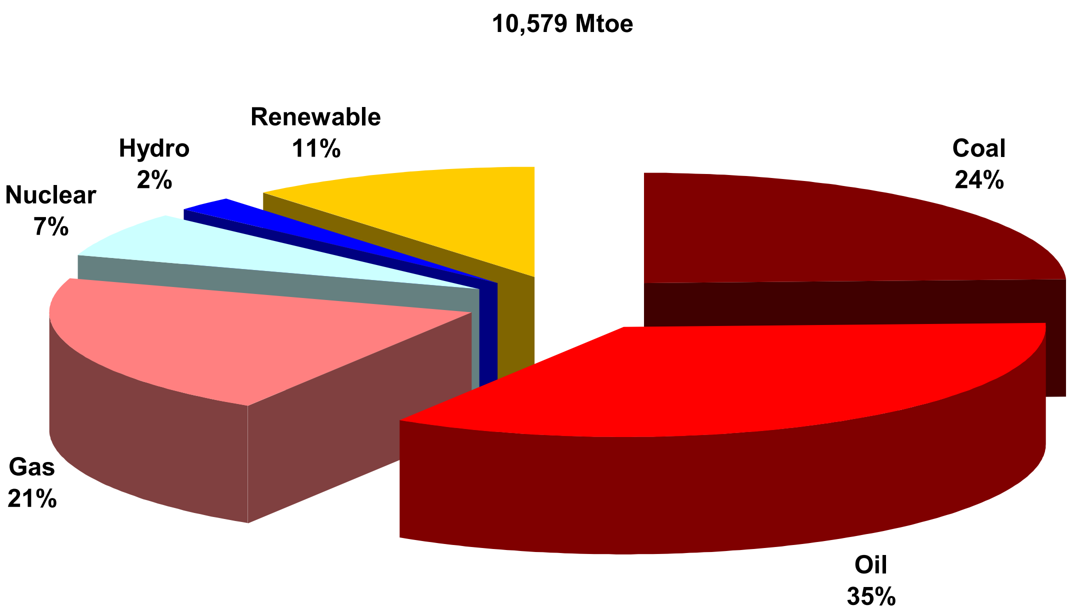
2. The Hydrogen Economy – What is it?

Worldwide demand for energy is growing at a high rate, with average growth of 1.8% per annum predicted for the period 2000-2030 for primary energy worldwide.

The Carbon Economy

The bulk of the energy which drives the world is derived from carbon products, principally fossil fuels. Hydrocarbons account for 80% of the world's primary energy supply; oil for 35%, coal for 24% and gas for 21%. More than half of the balance, 11% is contributed by renewables, almost all in the form of renewable biomass. Biomass emits carbon and other greenhouse gases when it is burned, but these are counter-balanced by the carbon which new plants consume when they grow to replace those that have been combusted. Nuclear power and hydro power, which do not produce carbon, contribute 9%. It is common to associate the use of carbon as a fuel with the Industrial Revolution which gave birth to the enormous economic development of the past two centuries. In fact carbon products, both renewable and fossilised, have always been used, but the volume of their consumption has increased exponentially with industrialisation.

Figure 2-1: Fuel Shares, Total Final Primary Energy Supply TPES



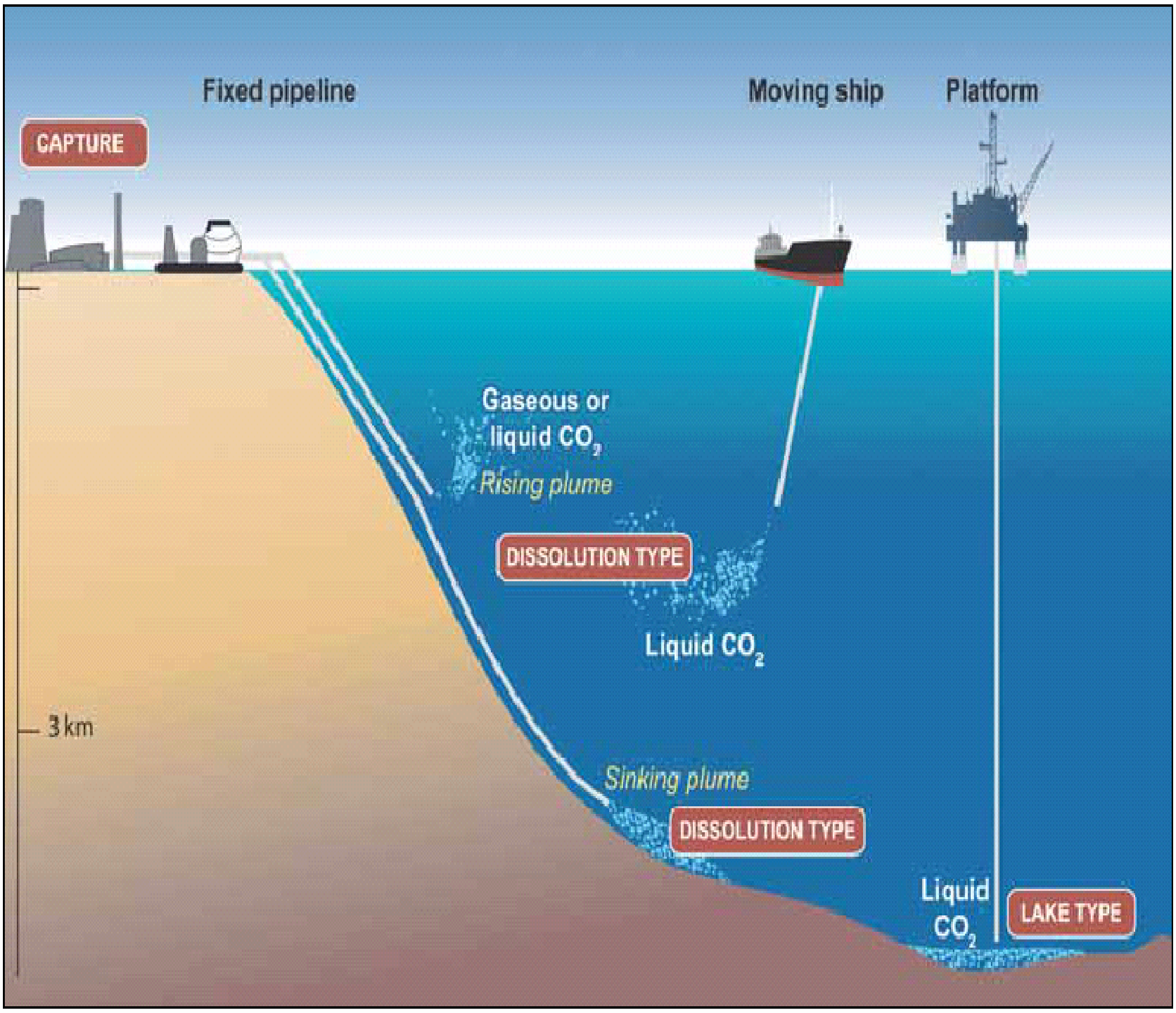
Source: EIA, IEA

The increased demand for energy is being met largely by reserves of fossil fuel that emit both greenhouse gasses and other pollutants. Those reserves are diminishing and they will become increasingly expensive. Hydrocarbon reserves are being depleted. According to traditionally used definitions of reserves, the world has only 40 years of oil left at current rates of consumption, 67 years of natural gas and 164 years of coal. The global energy community is currently engaged in debate about the extent of the world's remaining petroleum reserves and the rate of their depletion. Traditional orthodoxy is being challenged and the actual definitions of the resource itself and of the term 'reserves' are under scrutiny.

There are two strands to the reassessment of the world's fossil fuel energy reserves. The definitions are themselves being reassessed. The rigour of most of the valuations is largely dependent on probabilities which are assigned to various factors, such as the likelihood of pipelines being available to a specific field. Discovered or known resources can be divided into proved reserves and prospective or unproved

Various options are being reviewed for ocean storage of captured CO2. In 'dissolution type' ocean storage, the CO2 rapidly dissolves in the ocean water, whereas in 'lake type' ocean storage, the CO2 is initially a liquid on the sea.

Figure 5-4: Ocean Storage Concepts for Captured Carbon



Source: UNEP, Intergovernmental Panel on Climate Change

Enhanced Oil Recovery (EOR)

Enhanced Oil Recovery merits particular attention in the UK context because it represents an appreciable storage option for CO2 while offering a financial return from the additional oil extracted from UK Continental Shelf reserves.

EOR may use CO2 to mobilise some of the oil remaining in a reservoir after primary and secondary production is complete. It does this by dissolving in the oil thereby reducing the oil's effective viscosity and making it more mobile. The movement of the CO2 from within the reservoir can then sweep the oil to the production wells. CO2 based EOR is an established onshore procedure in North America but has not yet been undertaken offshore.

7. Hydrogen Production, Volume and Producers

Global Production

There is an established infrastructure for hydrogen production and delivery today to meet the needs of industrial applications including chemical production, metals processing, refining, fats and oils production and electronics processing. Global production is commonly estimated at approximately 50 Million tonnes (Mt) or 500 billion Nm^3. This is enough hydrogen to fuel 250 million fuel cell cars. Global statistics of hydrogen production are erratic and the estimates vary because 95% of the hydrogen produced in the world is manufactured for captive use in industrial processes. Only 5% is manufactured for sale by merchant producers. Almost half the total, 48%, is produced by steam reforming of natural gas, 30% from oil and 18% from coal. Only 4% is produced by electrolysis.

Table 7-1: Production of Hydrogen by Source

	Nm3 billon	Million tonnes (Mt)	%
Natural gas	240	24	48%
Oil	150	15	30%
Coal	90	9	18%
Electrolysis	20	2	4%
	500	50	100%

Source: DOE

The largest producers are the US and China, which together account for approximately one third of global production, 18% and 16% respectively. The next highest recorded is Germany with 6%, followed by the UK and France with 3% and 2%.

Table 7-2: Half of the Hydrogen is Produced in the US, China and the EU.

	Mt	%
US	9.00	18%
China	8.00	16%
Europe	7.10	14%
Germany	2.98	6%
UK	1.35	3%
France	0.78	2%
Italy	0.64	1%
Spain	0.28	1%
Austria	0.21	0%
Other Europe	0.92	2%
Japan	1.55	3%
ROW	17	34%
	50	100%

Source: DOE, ISO/TC

Merchant hydrogen production in the US grew by 9.5% a year from 1997 to 2002 and then by 10% a year to 2006. This was considerably higher than for captive hydrogen and the total growth of hydrogen, including merchant and captive, was 4% a year up to 2006.

Merchant and Captive

Captive hydrogen production is spread among a large number of companies.

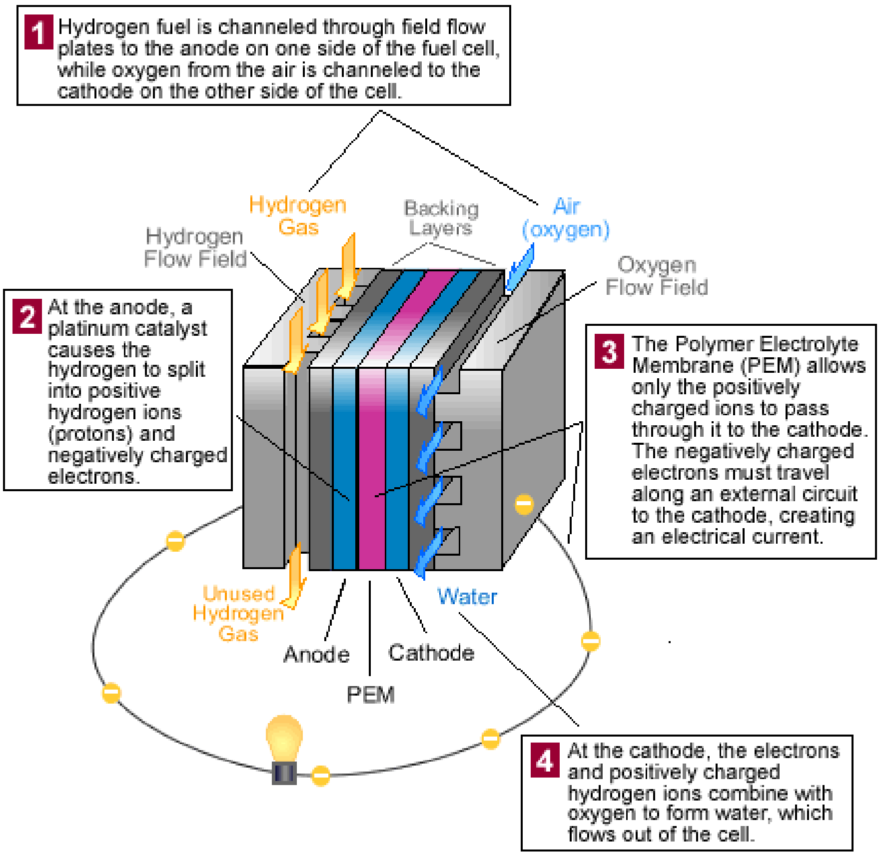
The merchant hydrogen industry is dominated by the four gas majors:

8. Fuel Cells, Types, Current Status and Applications of Each Type

What is a Fuel Cell?

Fuel cells produce energy without combustion by an electrochemical process using hydrogen fuel. A fuel cell consists of two electrodes, a negative anode and a positive cathode, sandwiched around an electrolyte. Hydrogen is fed to the anode and oxygen (from the air) to the cathode. Encouraged by a catalyst, the hydrogen atom splits into a proton and an electron. The proton passes through the electrolyte. The electrons create a separate current that can be utilised before they are reunited with the hydrogen and oxygen to form water molecules.

Figure 8-1: Fuel Cell Concept



Source: FuelEconomy.Gov

When a fuel cell system is equipped with a 'fuel reformer,' the fuel cell can utilise hydrogen from a number of hydrocarbon fuels including natural gas, methanol, propane, biomass, and gasoline. In principle, any hydrogen compound will do. The emissions from reforming these various hydrocarbon fuels would still be cleaner than those from a combustion process. It is also possible to obtain hydrogen by separating water in an electrolyser, or by extracting it from a compound that contains no carbon, such as ammonia or boron compounds.

Fuel cells are a family of technologies, characterised by their electrolytes and temperature of operation. Different technologies will be suitable in different applications. At present, PEMFCs and SOFCs are

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