UKERC

UKERC RESEARCH ATLAS: HYDROGEN

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1. Overview

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Characterisation of the field

Hydrogen is a major industrial chemical currently used in oil-refining, ammonia synthesis, food-processing, etc.

This document is concerned with hydrogen's potential as an important alternative fuel to replace hydrocarbon fuels in future "low carbon" energy systems. The term "hydrogen energy" covers all aspects of the use of hydrogen in energy systems, from the production of hydrogen from primary or secondary fuels, through the storage and distribution of hydrogen, to the end-use of hydrogen (usually but not exclusively in fuel cells) in stationary, transport, and portable applications. Fuel cell research is covered under a separate fuel cells landscape document. This landscape covers all other aspects of hydrogen research.

Hydrogen is an energy carrier, complementary to electricity and carbon-free at the point of use. It can be produced in many ways, including steam-reforming of natural gas (approximately 95% of current production), biomass gasification, and electrolysis of water, with the overall carbon emissions from the fuel chain depending on the primary fuel used and any associated carbon capture and storage processes. Novel sustainable production routes are being studied including fermentation processes, photo-electrolysis and thermo-chemical cycles driven by solar or nuclear heat.

Hydrogen has the highest energy density per unit mass of any chemical fuel, but its low density results in a comparatively low energy density per unit volume. For stationary applications, hydrogen can be stored more easily than electricity. For mobile applications, space restrictions and hydrogen's low density result in potentially unacceptable restrictions to vehicle range. Conventional solutions such as hydrogen liquefaction (energy intensive, requiring at least 30% additional energy) and hydrogen compression (very high pressures >700 bar needed to maintain conventional vehicle range) have net energy and safety implications, so research is focussing on solid-state storage using, for example, metal hydrides.

The socio-economic and environmental "whole system" impact of hydrogen, including transition scenarios, required infrastructural development, potential support mechanisms, and consumer attitudes, are important research topics. While hydrogen is generally considered for mobile applications, it has a wider potential role in grid-balancing, alongside other technologies.

Research Challenges

A hydrogen energy system, at any scale, must be justified in terms of its economic advantage or significant environmental benefit. In both the stationary heat/power and transport markets, hydrogen and fuel cells will have to compete with incumbent fuel technologies (natural gas and petroleum) with fully developed infrastructures. Early support through demonstration and, at a later date, suitable designed incentives would be necessary to move towards a diverse energy system involving hydrogen. A key research challenge is to assess the "whole system" viability of such low carbon energy economies and their socio-economic and environmental costs and benefits.

At the same time, there remain significant technical challenges in hydrogen-based low carbon pathways, namely:

(i) development of compact on-board hydrogen storage systems (ideally adsorbed in or on a lightweight solid medium for safety and energetic reasons);

(ii) development of sustainable bulk hydrogen production pathways.

2. Capabilities Assessment

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Hydrogen and fuel cells technologies promise low carbon, clean energy solutions at all scales within the energy system. Their potentially disruptive nature and problems of integration with the existing energy system has led to major international research programmes and "road-mapping" activities. Major international programmes include the European Commission's investment in the Fuel Cells and Hydrogen Joint Undertaking (see: http://www.fch-ju.eu/) and the Department of Energy's Hydrogen and Fuel Cells Program in the United States (see: http://www.hydrogen.energy.gov/).

The UK government has maintained a "watching brief" for some years and acted to underpin the research base with major projects funded through the EPSRC: Supergen Hydrogen Energy Consortium (UK-SHEC), Supergen Delivery of Sustainable Hydrogen and the more recent formation of the Hydrogen and Fuel Cell Supergen Hub. A recent meeting of leading UK hydrogen researchers convened by the UKERC at the Meeting Place[1] concluded that the UK hydrogen research community has "relatively few gaps" and an "appropriate range of knowledge/skills and activities to address future challenges". However, hydrogen and fuel cells are not currently considered either a short or medium term development priority for the UK government (see, for example, the lack of substantial mention in Planning our electric future: a White Paper for secure, affordable and low-carbon electricity, July 2011) and the UK "lags badly behind Germany, the United States and Japan"[1] with regard to the kind of large scale demonstration projects required to capitalise on the UK knowledge base and develop native commercial expertise.

In 2010, the Energy Research Partnership commissioned a report[2] from the Fuel Cell and Hydrogen Group of the Energy Generation and Supply Knowledge Transfer Network (EG&S KTN) to review the level of UK international engagement in fuel cells and hydrogen. This study, performed by Synnogy on behalf of the EG&S KTN concluded with a Capability Matrix reproduced below.

The EG&S KTN report updated a previous study[3] carried out by Eoin Lees Energy, E4Tech and Element Energy on behalf of the DTI: "A strategic framework for hydrogen energy in the UK" (2004), summarising the main strengths and weaknesses of UK activities throughout the hydrogen energy chain. Specifically for hydrogen R&D, the report identified work at national and international level in hydrogen production, storage, distribution, and conversion, although specific projects were not identified. An interpreted summary of these findings is given in table 2.

UK role in international engagement in hydrogen and fuel cells in 2010 – capability matrix

Collaborate and share: contributing equally to development of the technology	**Lead: accelerating technological progress and securing a competitive advantage for the UK**
• Hydrogen safety, pipelines, materials (R&D) • SOFC components (R&D) • Electrolysers working with intermittent energy source and at part load (R&D) • Equipment for production, storage or transport of hydrogen (Deployment) • Stationary and automotive reformer systems • Applications for remote communities (D&D) • PEMFC systems for niche applications, early markets and stationary power • Service provision for demonstration	• Hydrogen storage8 (Research) • Novel hydrogen production techniques (R&D, D) • Large SOFC systems for power generation • Small SOFC systems for stationary applications • Components (BoP, DMFC, PEMFC, MEAs, reformer systems, bipolar plates) • Novel catalysts • Novel PEMFC systems • PEMFC systems for automotive applications in specific circumstances • Integrated Energy Systems • Socio-economic studies (Research)
• Internal combustion engines operating on hydrogen (Demo)	• DMFC systems
Watch: playing a minor role in development but being aware of implications for the UK	**Follow and learn: developing capability in the UK to develop and/or deploy the technology**

References:

1 **UKERC The Meeting Place (2011),** "UK Hydrogen Researchers' Workshop", 28 February 2011 (available from: http://www.ukerc.ac.uk/support/tiki-index.php?page_ref_id=2847)

2 **Synnogy Ltd (2010).** "Assessment of UK international engagement in fuel cells and hydrogen" (available from: https://connect.innovateuk.org/c/document_library/get_file?folderId=206940&name=DLFE-17901.pdf)

3 **Eoin Lees Energy, E4Tech, Element Energy (2004).** "A strategic framework for hydrogen energy in the UK" (available from http://webarchive.nationalarchives.gov.uk/+/http://www.berr.gov.uk/files/file26737.pdf)

Table 2.1 UK Capabilities

UK Capability	Area	Market potential
High	Hydrogen production (dark fermentation) Materials for hydrogen storage (metal hydrides; complex hydrides; porous materials) Renewable energy systems Socio-economic analysis	Global (medium/low impact) Global (high impact) Global (high impact) Global (high impact)
Medium	Materials for hydrogen production Hydrogen production (other) Hydrogen storage (devices) Hydrogen distribution	Global (high impact) Global (high impact) Global (medium impact) UK application (low impact)
Low	Hydrogen infrastructure Hydrogen systems Reversible fuel cells	UK application (high impact) Global (high impact) Global (medium impact)

3. Basic and applied strategic research

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The major EPSRC funding streams relevant to hydrogen are the Hydrogen and Fuel Cell SUPERGEN Hub (and associated Grand Challenge calls) and the Doctoral Training Centre in Hydrogen, Fuel Cells and their Applications at the University of Birmingham.

The H2FC SUPERGEN Hub is led by Professor Nigel Brandon of Imperial College London, and also involves researchers from University of St Andrews, University of Bath, University of Birmingham, University of Ulster, Newcastle University, and University College London. The core programme of research consists of nine work packages, that cut across policy and socio-economics, systems, safety, and education and training, along with key aspects of underpinning science and technology, namely hydrogen production, hydrogen storage, PEM fuel cells, and solid oxide fuel cells/electrolysers, integrating these together in a final research synthesis work package. The core programme will be backed up by additional projects linked to the Hub and funded through the EPSRC Grand Challenge mechanism.

The H2FC SUPERGEN Hub consolidates work by previous SUPERGEN consortia funded separately in hydrogen and fuel cells, thereby now encompassing the whole energy chain. In fact there were two purely hydrogen research consortia operating until 2012-13: 1) Supergen UK Sustainable Hydrogen Energy Consortium (UK-SHEC) and 2) Supergen Delivery of Sustainable Hydrogen.

The UK-SHEC programme concentrated on hydrogen storage (Oxford, Birmingham, Nottingham, UCL, Bath, STFC, Glasgow), with one university (Glamorgan) contributing on hydrogen production from dark fermentation processes and a cross-cutting socio-economic theme (UCL Energy Institute, Salford, Manchester Business School, Strathclyde, Durham).

The Delivery programme focused on hydrogen production, with research themes in hydrogen from carbon sources: ceramic membranes (Newcastle), plasma catalysis (Manchester), hydrogen from alcohols (Warwick), advanced steam reforming (Leeds), hollow-fibre micro-reactors (Imperial College), carbon dioxide (Oxford); hydrogen from electrical sources: high temperature steam electrolysis (St Andrews), alkaline electrolysis (Strathclyde), electrochemical synthesis of ammonia (Strathclyde); separation technologies (Cardiff, Birmingham); scalable liquefaction (Cambridge); and socio-technical analysis (Cardiff, Imperial College).

Additional hydrogen-related projects are funded directly under the EPSRC's responsive mode. An overall assessment of the hydrogen research area in the EPSRC energy portfolio is available on the internet; this was last updated in April 2011.

Table 3.1: Research Funding

Programme	Funding Agency	Description	Committed Funds	Period	Representative Annual Spend
SUPERGEN UK-SHEC Phase 2	EPSRC	1. Theme 1: Hydrogen Production; 2. Theme 2: Hydrogen Storage; 3. Theme 3: Integrated Systems; 4. Theme 4: Demand, Innovation, Deliberation and Sustainability; and 5. Theme 5: Management.	£5.94m	2007-12	(£1.19m)
SUPERGEN Delivery of Sustainable Hydrogen	EPSRC	Working on a wide range of technologies that can potentially produce hydrogen using less energy and predominantly intermittent renewable energy sources at a variety of scales.	£4.9m	2008-13	(£1.0m)
Hydrogen and Fuel Cell SUPERGEN Hub	EPSRC	The Hydrogen and Fuel Cells (HFC) SUPERGEN Hub seeks to address a number of key issues facing the hydrogen and fuel cells sector specifically: (i) to evaluate and demonstrate the role of hydrogen and fuel cell research in the UK energy landscape, and to link this to the wider landscape internationally, and (ii) to identify, study and exploit the impact of hydrogen and fuel cells in low carbon energy systems.	£4.0m	May 2012 – April 2017	£0.8m
SUPERGEN Hydrogen and Fuel Cells Challenge	EPSRC		Up to £5.0m (announcement pending)	2013-2017	£1.25m
Doctoral Training Centre in Hydrogen, Fuel Cells and their Applications	EPSRC	Interdisciplinary research in hydrogen and fuel cells including Chemical Engineering, Chemistry, Materials Science, Economics, Bioscience, Applications, Automotive and Aeronautics, and Policy/Regulation	£5.5m	2009-2018	£0.5m

Responsive mode	EPSRC	Various projects	£8.7m (calculated from EPSRC assessment of hydrogen and alternative energy vectors spend (2011) after subtraction of SUPERGEN consortia)	ongoing	£2.9m

Table 3.2: Key Research Providers

Name	Description	Sub-topics covered	Number of Staff	Field
Robert Gordon University, Aberdeen	The University has four key research themes: Health and Welfare, Energy and the Environment, Creative Industries, Knowledge Economy	**Hydrogen Production** • Hydrogen production by electrolysis from tidal power generation		Mechanical , Aeronautical and Manufacturing Engineering
School of Biosciences, University of Birmingham	Biological production of hydrogen	**Hydrogen Production** • Biological hydrogen production from crops and sugar wastes		Biological Sciences
Theory, Modelling and Informatics Interest Group, Department of Chemistry, University of Cambridge	The theoretical research and modelling carried out at CUC³ covers a broad range of topics in theoretical and quantum chemistry, condensed matter physics, surface science, and statistical mechanics of complex and disordered systems including macromolecular aggregates.	**Hydrogen Production** • Quantum chemistry, intermolecular forces and spectroscopy		Chemistry
Cambridge Synthesis Centre, Department of Chemistry, University of Cambridge	Development of artificial photosynthetic systems, which either mimic photobiological energy generation and/or incorporate enzymes directly in biotechnologically relevant hybrid systems	**Hydrogen Production** • Artificial photosynthesis • Biomimetic chemistry • Redox catalysis		Chemistry
Department of Chemical Engineering, University of Cambridge	Combustion group interested in gasification of biomass and waste materials and operation of fluidised beds	**Hydrogen Production** • Distributed hydrogen production with carbon capture: a novel process for the production of hydrogen from biomass		Chemical Engineering
School of	Recover and purify hydrogen for	**Hydrogen Production**		Chemical

Name	Description	Sub-topics covered	Number of Staff	Field
Engineering, University of Edinburgh	industrial gas streams	• Nano-porous adsorbents • Hydrogen purification		engineering
Energy & Resources Research Institute, University of Leeds	The Energy and Resources Research Institute (ERRI) is a major pioneering force of international standing within the disciplines of energy and resources.	**Hydrogen Production** • Hydrogen production from vegetable oil • Hydrogen generation from biomass derived glycerol using sorption enhanced reaction processes • Unmixed Steam Reforming of Liquid Fuels From Biomass and Waste for Hydrogen Production		Chemical Engineering
Department of Chemistry, University of Liverpool	Photocatalysis	**Hydrogen Production** • Doped metal-oxide nanotubes		Chemistry
Energy Futures Lab, Earth Science & Engineering, Imperial College London		**Hydrogen Production** • Photo-catalytic and photo-biological routes to hydrogen		Materials Chemistry
Department of Materials, Imperial College London	Research in the Department is centred around four main themes: Biomaterials, Ceramics and Glasses, Metals and Nanotechnology	**Hydrogen Production** • Intermediate temperature solid oxide electrolysers for hydrogen production		Metallurgy and Materials
The Centre for CO_2 technology, Department of Chemical Engineering, University College London (UCL)	The Centre focuses on developing break-through technologies for the large scale reduction (e.g. alternative, low carbon, energy sources), removal (e.g. gas separation from flue emissions) and sequestration (e.g. long term storage in geological, terrestrial, and ocean systems) of carbon dioxide. Technologies for methane, the second most important greenhouse	**Hydrogen Production** • Hydrogen production from steam gasification of biomass		Chemical engineering

Name	Description	Sub-topics covered	Number of Staff	Field
	gas, are also being developed.			
Hydrogen Research Unit, Sustainable Environment Research Centre, University of Glamorgan	The Sustainable Environment Research Centre (SERC) investigates wastewater treatment and hydrogen production and use and has a well-equipped research laboratory	**Hydrogen Production** • H2 Wales • Hydrogen production by fermentation • Feasibility of Sustainable Hydrogen Production from Starch Industry co-products (Carbon Trust) • Hydrogen production from wheat industry co-product (Carbon Trust) • Other biological hydrogen production		Biological Sciences
Department of Chemistry, Loughborough University	Solar hydrogen	**Hydrogen Production** • Materials • Devices • Characterisation		Chemistry
School of Chemical Engineering & Advanced Materials, Newcastle University	PI of SUPERGEN: Delivery of Sustainable Hydrogen	**Hydrogen Production** • High temperature ceramic membranes • Intermediate temperature proton-conducting membrane systems • Syngas and hydrogen separation		Chemical engineering
Inorganic Chemistry Laboratory, Department of Chemistry, University of Oxford	The Laboratory is leading the UK Sustainable Hydrogen Energy Consortium (Supergen)	**Hydrogen Production** • Hydrogen production from hydrogenases		Chemistry
Process Fluidics Group, Chemical & Biological Engineering, University of Sheffield	The work of the Group has 5 strands: Microfluidics and microchemical Engineering, Biophysicochemical hydrodynamics, Hydrogen production, Green chemistry, Power fluidics	**Hydrogen Production** • Hydrogen production from thermo-chemical cycles		Chemical Engineering

Name	Description	Sub-topics covered	Number of Staff	Field
Engineering and the Environment, University of Southampton	Photocatalysis	**Hydrogen Production** • Titanate nanotubes		Chemistry
Chemistry, University of St Andrews	Production of hydrogen through electrolysis	**Hydrogen Production** • Technical lead partner for SUPERGEN: Delivery of Sustainable Hydrogen		Chemistry
Photocatalysis Research Group and Nanotechnology and Integrated Bioengineering Centre, Faculty of Engineering, University of Ulster	The group aims to develop multi-layered semiconductor electrodes for the photo-splitting of water to give O_2 and H_2 under solar illumination.	**Hydrogen Production** • Multi-layered semiconductor electrodes for the direct photo-splitting of water		Chemistry Metallurgy and Materials
Department of Chemistry, University College London (UCL)	Nanocrystalline photodiodes	**Hydrogen Production**		
Synthetic Chemistry, Department of Chemistry, University of Warwick	Science Cities: Hydrogen energy project	**Hydrogen Production** • Hydrogen generation from biomass • Hydrogen storage – methodology and characterisation • Energy from hydrogen using fuel cells		Chemistry
Department of Chemistry, University of York	The interests of the group encompass materials and molecular chemistry, particularly the synthesis of molecules that exhibit interesting reactivity or catalytic activity and unusual routes to solid materials with photocatalytic application.	**Hydrogen Production** • Photocatalytic splitting of water		Chemistry

Name	Description	Sub-topics covered	Number of Staff	Field
Adv. Materials and Porous Solids research group, Department of Chemical Engineering, University of Bath	The group is particularly prominent in the development of special carbon structures and porous oxides and structured adsorbents, which are used for hydrogen storage	**Hydrogen Storage** • Synthesis of structured porous solids for use as gas storage media (silica, MOF). • One year research in TiO_2 nanotubes and application for H2 storage • Complex porous structures in carbons • Hydrogen storage in nanoporous carbons • Carbon nanotubes; molecular simulation • Microporous membranes, carbons for gas storage • Rhodium hydride clusters		Chemical engineering Metallurgy and Materials
Department of Chemistry, University of Bath	Structural chemistry of hydrogenous materials	**Hydrogen Storage** • Neutron scattering from hydrogen containing compounds • Redox switchable hydrogen storage materials		Chemistry
Centre for the Theory and Application of Catalysis (CenTACat), School of Chemistry and Chemical Engineering, Queen's University of Belfast	CenTACat undertakes multidisciplinary research involving chemists, physicists and engineers with a common interest in understanding the fundamental principles that underpin clean energy production, clean organic chemistry, and environmental protection	**Hydrogen Storage** • Porous Metal Organic Frameworks (MOF) and nanoscale coordination cages for chemical separation or storage technology • Microporous solids Hydrogen Storage • Reforming liquids (ethanol, water, oils) via catalysis for production of H_2; storing as a liquid		Chemistry Chemical Engineering
School of Chemistry, The University of Birmingham	Member of UK-SHEC Novel materials for hydrogen storage.	**Hydrogen Storage** • Development of advanced hydrogen storage materials: chemical activation of		Chemistry

Name	Description	Sub-topics covered	Number of Staff	Field
		magnesium-based alloys; synthesis of complex hydrides; synthesis of ion-exchanged zeolites • Fuel cell and hydrogen store for integration into automobiles (FUCHSIA) – EC Framework Programme 5 (ended April 2005)		
Hydrogen Materials Group, Department of Metallurgy and Materials, School of Engineering, The University of Birmingham	Member of UK-SHEC Member of EC FP6 NESSHY Novel materials for solid-state hydrogen storage; use of hydrogen as a processing tool for functional materials, such as rare-earth magnets; hydrogen energy demonstration projects.	**Hydrogen Storage** • Development of advanced hydrogen storage materials: nanostructured magnesium-based alloys; complex hydrides, including borohydrides; nano-structured graphitic materials; metal organic framework materials (with project partners); zeolites (with the School of Chemistry); polymer-based hydrogen storage Materials (with Cardiff University and Manchester University) • Hydrogen purification and separation: novel alloys for dense metal membranes; development of porous substrates for metal membranes • Hydrogen processing of functional materials (e.g. rare-earth magnets, structural materials, etc.) • Development of prototype solid-hydrogen stores (for lab use, and in hydrogen demonstration systems)		Chemistry Metallurgy and Materials

Name	Description	Sub-topics covered	Number of Staff	Field
School of Chemistry, Cardiff University		**Hydrogen Storage** • Polymer-based hydrogen storage materials (with Univ. of Manchester and Univ. of Birmingham) • Potential of organic crystals as hydrogen storage materials		
ISIS, STFC Rutherford Appleton Laboratory, Didcot	The world's leading pulsed neutron and muon source for research in physics, chemistry, materials science, engineering, and biology.	**Hydrogen Storage** • TOSCA neutron spectrometer used to study metal hydrides (binary, tertiary and catalysed/doped), zeolites, MOFs, metal oxide structures, nanotubes, doped graphite, Li_3N, molecular solids, etc. • Computational/experimental capability for data interpretation and prediction of thermodynamic properties		Metallurgy and Materials
Department of Chemistry, University of Glasgow	Synthesis, structure and physical properties of inorganic solids	**Hydrogen Storage** • Member of UK-SHEC		Chemistry
Department of Chemistry, University of Liverpool		**Hydrogen Storage** • H_2 storage in carbon nanotubes • Hydrogel nanoclathrates		Chemistry
Department of Chemistry, University College London (UCL)	High throughput inorganic nanomaterials discovery	**Hydrogen Storage** • Complex oxide catalysts		Chemistry
Department of Physics and Astronomy, Condensed Matter and Materials physics, University College London	The group is investigating novel carbon-based materials for reversible hydrogen storage, hopefully up to and above the 6% by weight required by the automobile industry.	**Hydrogen Storage** • Theoretical studies of adsorption and diffusion of small molecules (CO_2) in porous materials (zeolites, flexible MOF for low-mass storage materials) • Carbonaceous materials and		Metallurgy and Materials

Name	Description	Sub-topics covered	Number of Staff	Field
(UCL)		gas storage • Molecular simulations in clay hydrates		
School of Chemistry, University of Manchester		**Hydrogen Storage** • Storage of H_2 in graphite nanofibres • Polymer-based hydrogen storage materials (with Cardiff University and Univ. of Birmingham)		Chemistry
Northern Carbon Research Laboratories, University of Newcastle	The Northern Carbon Research Laboratories (NCRL) are part of the School of Natural Sciences, specialising in the study of all aspects of carbon science.	**Hydrogen Storage** • Carbon science • Nano-porous materials for hydrogen storage		Chemistry
School of Environmental Sciences, University of East Anglia (UEA), Norwich		**Hydrogen Storage** • Hydrogen Storage in Solid-Form, • Nanostructural Materials Synthesis		Chemistry Metallurgy and Materials
Advanced Materials Research Group, School of Mechanical Materials and Manufacturing Engineering, University of Nottingham	The Advanced Materials Research Group carries out research at the forefront of materials processing, and at the interface of materials science and engineering. Their research is underpinned by 'state-of-the-art' materials processing, and characterisation facilities and infrastructure.	**Hydrogen Storage** • Catalysed light metal hydrides • Catalysed complex hydrides • Graphitic Nanofibres (GNFs) • Metallo-Organic Framework Polymers (MOFs) • Ternary BCC • Design of storage systems • Hydrogen storage in carbon materials • Metal hydrides and metal carbides • Construction of Transition Metal chains, sheets and matrices (Ni, Cu Zn with N- and S- bridging ligands). • Mesoporous molecular sieves • Preparation of coordination		Chemical Engineering Metallurgy and Materials

Name	Description	Sub-topics covered	Number of Staff	Field
		framework polymers and networks, micro-and meso-porous materials for H_2 storage. • Metal hydrides (lithium nitrides/amide/imides)		
School of Chemistry, University of Nottingham	The common feature of Inorganic Chemistry at Nottingham is the use, study and understanding of novel molecular interactions or unusual synthetic or engineering procedures to yield new compounds, properties, catalysis and function.	**Hydrogen Storage** • Crystal Engineering (coordination porous framework structures, organic-inorganic hybrid materials for use in H_2 storage		Chemical Engineering Metallurgy and Materials
Advanced Materials Research Group, School of Chemical, Environmental and Mining Engineering, University of Nottingham	The programme of research in advanced carbon materials encompasses carbon nanotubes and fibres, hydrogen storage for fuel cell applications and coal carbonisation.	**Hydrogen Storage** • Hydrogen storage on carbon nanofibres and related materials		Chemical Engineering Metallurgy and Materials
Inorganic Chemistry Laboratory, Department of Chemistry, University of Oxford	The Laboratory is leading the UK Sustainable Hydrogen Energy Consortium (UK-SHEC) within EPSRC's Supergen programme. The laboratory covers coordination and organometallic chemistry, catalysis, solid-state and surface chemistry, electrochemistry, the study of proteins, enzymes and the role of magnetic species in biological systems, hydrogen production from hydrogenases, and the application of a variety of spectroscopic and diffraction techniques.	**Hydrogen Storage** • Metal hydrides • Carbons • Materials for H_2 storage		Chemistry
Institute for Materials Research, University of Salford	The Institute was established in 1999 to provide a focus for research on materials at the University. Its members, both scientists and engineers, are active in the	**Hydrogen Storage** • Zeolites/carbonaceous materials; computational modelling of hydrides • Carbon Nanotubes; neutron		Chemistry Metallurgy and Materials

Name	Description	Sub-topics covered	Number of Staff	Field
	development, characterisation and exploitation of new materials, both structural and functional.	scattering with hydrogen as a surface probe; complex lightweight hydrides • Computational studies of Metal hydride systems; • Hydrides and Carbon nanotubes; X-ray neutron diffraction (and powder X-ray)		
Research Institute for Industry, University of Southampton	The Research Institute for Industry, RIfI, is a cutting edge applied research organisation able to support and collaborate with industry in the specialist fields of engineering.	**Hydrogen Storage** • Hydrogen storage by sorption in TiO_2 nanotubes • Borohydride fuel cells and redox flow cells		Chemistry Metallurgy and Materials
School of Chemistry, University of St. Andrews	The focus of the Materials activity is clustered around the St Andrews Centre for Advanced Materials. This grouping brings together those working in Energy Materials, Porous Solids, Catalysis and Surface Science as well as physicists and geoscientists. There is a significant level of applied research interfacing with new battery technologies and Materials for Clean Energy.	**Hydrogen Storage** • High temperature electrolysis of water using solid oxide proton conductors • MOF and zeolites for the storage of NO.		Chemistry
Department of Chemistry, University of Warwick		**Hydrogen Storage** • Metallic nanoparticles for hydrogen storage		Chemistry
Future Power Systems Group, School of Mechanical Engineering, University of Birmingham	Combustion and energy conversion technologies, alternative fuels and hydrogen	**Hydrogen End-use** • exhaust gas and autothermal fuel reforming		
School of Engineering and	Clean low carbon vehicles	**Hydrogen End-use** • engine combustion,		Automotive

Name	Description	Sub-topics covered	Number of Staff	Field
Design, Brunel University		• performance and emissions under simulated conditions with addition of N_2-H_2 mixtures		engineering
Department of Chemistry, Cardiff University	Clean low carbon vehicles	**Hydrogen End-use** • Catalysis of reforming reactions at moderate temperature		Chemistry
Mechanical Engineering, University of Bath	Transition pathways to a low carbon economy	**Cross-cutting and whole systems**		Engineering
Doctoral Training Centre in Hydrogen, Fuel Cells and their Applications, The Universities of Birmingham, Loughborough & Nottingham	The Birmingham Fuel Cells Group has recently been awarded £5million (EPSRC) for the creation and running of a Doctoral Training Centre in Hydrogen, Fuel Cells and their Applications, the first of its kind in the UK.	**Cross-cutting and whole systems**		
Centre for Environmental Policy, Imperial College London	The Centre for Environmental Policy provides a unique interface between science and technology and the economic and policy context in which it is developed and applied. Its focus is on environmental and development issues, including energy, pollution, conservation of natural resources, food security and poverty reduction.	**Cross-cutting and whole systems** • UK hydrogen policy		Politics and International Studies
Centre for Fire & Explosion Studies, Faculty of Science, Engineering and Computing, Kingston University	Hydrogen fire safety	**Cross-cutting and whole systems** • Fire and explosion modelling • Environmental flow modelling		Safety
Environment Group, Policy Studies Institute (PSI), London	PSI is an independent research institute, conducting research to promote economic well-being and improve quality of life. PSI has a	**Cross-cutting and whole systems** • Socio-economic issues • Modelling of energy systems		Sociology Economics and Econometrics

Name	Description	Sub-topics covered	Number of Staff	Field
	reputation for the rigorous and impartial evaluation of policy in the UK and Europe.	• Public perception		
Department of Chemical Engineering, Loughborough University	Research work is focused on specialist areas including product engineering, advanced separation technologies, and safety, environment and loss prevention.	**Cross-cutting and whole systems** • Hydrogen safety • Natural gas – hydrogen mixtures • NaturalHy participant		Chemical Engineering
Centre for Sustainable Urban and Regional Futures (SURF), **University of Salford**	SURF is a mainly self-financing inter-disciplinary research centre. The Centre is part of the Research Institute for the Built and Human Environment (BuHu).	**Cross-cutting and whole systems** • ***Hydrogen futures*** • ***Socio-economic issues***		Sociology Economics and Econometrics
Built Environment Research Institute, **University of Ulster**	Hydrogen safety	**Cross-cutting and whole systems**		Built environment Safety

4. Applied research

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Applied research in the hydrogen energy sector is largely undertaken by groups within the large commercial gas supply companies and a range of start-up and small-medium-sized enterprises (SMEs).

Funding for hydrogen applied research, development, and demonstration has largely been through isolated project grants – historically via DTI and BERR, and recently from the Technology Strategy Board (TSB) – and intermittent attempts to initiate a hydrogen demonstration programme. Additional, local funding has been provided through the former Regional Development Agencies (RDAs) and the regional assemblies in Scotland and Wales.

Current responsibility for hydrogen demonstration funding largely resides with the Department for Energy and Climate Change (DECC) in cooperation with the Technology Strategy Board (TSB).

For demonstration of end-uses of hydrogen in clean vehicles and refuelling technologies see the Transport Landscape.

Table 4.1: Research Funding

Programme	Funding Agency	Description	Committed Funds	Period	Representative Annual Spend
Accelerating the introduction of fuel cells and hydrogen energy systems	Technology Strategy Board (TSB) / Department for Energy and Climate Change (DECC)	Five demonstration projects: • UK's first end-to-end, integrated, green hydrogen production, distribution and retailing system, centred around a 700 bar renewable H_2 refuelling station network across London (Air Products plc) • Delivery of solar energy generated hydrogen for Swindon's existing public access H_2 refuelling station via an electrolyser, and its use in materials handling vehicles and light vans at Honda's manufacturing plant (BOC Ltd) • Integration, on the Isle of Wight, of an electrolyser based refueller with renewable energy, enabling zero carbon	£9.0m (from TSB out of total project value in excess of £19.0m)	2013-?	

		hydrogen to be produced for use as a transport fuel for a range of vehicles (ITM Power) • Demonstration of a viable solar-hydrogen energy system, with benefits shared by multiple end users of a business park in Surrey, through the 24/7 provision of green electricity and heat (Rutland Management Ltd). • Demonstration of a whole renewable hydrogen system, connecting a 1MWe electrolyser to the grid, in conjunction with an Aberdeenshire wind farm, to explore the grid impacts and energy storage potential of hydrogen generation, and to provide the green hydrogen produced to power a fleet of fuel cell buses (SSE PLC)			
Renewable Hydrogen and Fuel Cell Support	Scottish Government	Provides grants to businesses or communities to deploy and demonstrate renewable hydrogen and fuel cell technology. The aim of the Renewable Hydrogen & Fuel Cell Support Scheme is to develop off-grid capacity and market opportunities / applications for renewable hydrogen and fuel cells in Scotland.	£1.5m		

Table 4.2: Key Research Providers

Name	Description	Sub-topics covered	Scale of Operation	Sector
Air Products	Air Products is a global industrial gases company, supplying gaseous and cryogenic liquid hydrogen	• Reaction chemistry • Materials chemistry • Engineering fundamentals • Applications development • Process engineering		Electricity and gas
AMEC	AMEC is a world leader in technical services and project management, employing around 44,000 people in some 40 countries around the world.	•		Consulting engineers
Auriga Energy	Auriga Energy specialises in the development of carbon free, highly efficient energy systems, utilising current and emerging fuel cell, for the marine, UPS/backup power and materials handling applications	• Bristol hydrogen ferry		Consulting engineers
BMW	Automotive manufacturer with interest in liquid hydrogen fuelled internal combustion engine (also dual-fuelled vehicles)			Manufacturing
Linde	Linde is a global industrial gases company with experience of building more than 200 plants for commercial hydrogen manufacture with capacities from 1,000 to over 100,000 Nm^3/h	• Design of the storage system for hydrogen fuel cell powered cars.		Electricity and gas
BP Gas & Power	One of the world's largest energy companies, providing fuel for transportation, energy for heat and light, retail services and petrochemicals products.	• world's first industrial scale project to generate electricity using hydrogen manufactured from natural gas		Electricity and gas Energy extraction
CERAM	CERAM is an international organisation with over 50 years of experience working for clients involved in ceramics and materials processing, the manufacture of ceramic components, or the			Manufacturing R&D science and

Name	Description	Sub-topics covered	Scale of Operation	Sector
	use of ceramic products.			engineering
C-Tech Innovation Ltd.	C-Tech Innovation Ltd. is an internationally renowned, development and consulting company, with over thirty years experience, in providing innovation services to companies, universities and governmental bodies.	• Enhancement of catalysis by a low energy electrochemical technique (Carbon Trust)		Consulting engineers
E4tech	E4tech is an international consulting firm specialising in sustainable energy, particularly bio-energy and hydrogen.	• Fuel cells & hydrogen energy • Biomass & waste for energy		Consulting engineers Management consultancy
Element Energy Ltd.	Element Energy Ltd. is an engineering company specialising in strategic energy consultancy and design and development services in the renewable and alternative energy sectors.	• Hydrogen • Low carbon technology		Consulting engineers
Fuel Cell Markets	Internet portal provider and management consultant to assist in the commercialisation of fuel cell, hydrogen, and sustainable energy technologies.	• Electrolysers • Fuel Storage		Management consultancy
Ilika	Ilika is a science-led materials discovery company using cutting edge high throughput techniques to create and characterise libraries of novel materials.	• Thin films, hydrogen storage alloys • Grand Challenge Hydrogen Storage (DTI project with Johnson Matthey, Rutherford Appleton Laboratory (ISIS), and University of Oxford)		R&D science and engineering
Ineos Chlor	A leader in the field of electrochemical technology licensing, electrolysis and fuel cells	• Electrolysers		R&D science and engineering
Intelligent Energy	An international company specialising in the	• Hydrogen production		R&D science

Name	Description	Sub-topics covered	Scale of Operation	Sector
	development of fuel cell and hydrogen generation technologies.			and engineering
ITM Power	ITM Power is an electrolyser and fuel cell company whose technology is based around a novel, low-cost, hydrophilic membrane	• Low-cost modular proton-exchange membrane electrolysers: a feasibility study (Carbon Trust)		R&D science and engineering
Johnson Matthey PLC, Catalysts Division	Johnson Matthey is a speciality chemicals company focused on its core skills in catalysts, precious metals and fine chemicals.	• auto-catalysts • catalysts and components for fuel cells.		Manufacturing
NRK Electrochem	NRK Electrochem offers a wide selection of mixed metal oxide, MMO, electro-catalytic coatings for the full spectrum of electrochemical processes.			Consulting engineers
Progressive Energy Ltd		• Coal gasification		Consulting engineers
Qinetiq	QinetiQ is one of the world's leading defence technology and security companies.	• Hydrogen storage (metal hydrides)		Consulting engineers
Ricardo–AEA	Energy and climate change consultancy	• Sustainable transport		Consulting engineers
Ricardo Consulting Engineers	Ricardo is a leading provider of technology, product innovation, engineering solutions and strategic consulting to the world's automotive industries. It combines business, product and process strategy with fundamental technical research and the implementation of large-scale new product development programmes.	• Fuel cell systems • Carbon to Hydrogen roadmap		Consulting engineers
Riversimple	Bringing the clean hydrogen car to the market			Car manufacture
Shell Global Solutions	Global group of energy and petrochemical companies.	• Hydrogen solutions provider		Electricity and gas
South West Electrolysers	South West Electrolysers is a UK based manufacturer of water electrolysis equipment for the production of hydrogen	• Electrolysers		Manufacturing
Stored Solar	Stored Solar (formed after the re-organisation of	• Photocatalytic		R&D science

Name	Description	Sub-topics covered	Scale of Operation	Sector
	Hydrogen Solar Ltd) is building a portfolio of hydrogen technologies and Intellectual Property aimed at the new hydrogen economy. The prime technology is the Tandem Cell™, which converts light and water directly into hydrogen fuel.	conversion of sunlight to hydrogen using the Tandem Cell (Carbon Trust)		and engineering

5. Development and Demonstration Funding

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There has been limited funding for hydrogen demonstration activities in the UK.

In London following the demonstration of 3 hydrogen fuel cell buses, partly supported through the EU CUTE programme, London Transport now operates several hydrogen buses on a commercial route. The project includes underground liquid hydrogen storage and a refuelling facility at BP's Hornchurch refuelling station. In Aberdeen it is planned that ten hydrogen buses will be introduced by 2014.

Table 5.1 Developments and Demonstration Funding

Programme	Funding Agency	Description	Committed Funds	Period	Representative Annual Spend
Hydrogen, Fuel Cells, Carbon Abatement Technology Demonstration Fund	DTI	The Hydrogen and Fuel Cell (H, FC) and Carbon Abatement Technologies (CAT) Demonstration Scheme is designed to address two of the Government's key energy priorities set out in the Energy White Paper: cost competitive carbon emissions reductions, and increased security of supply.	£50m (approximately £15m for hydrogen and fuel cells)	2007-11	
Hydrogen & Fuel Cell Demonstration Programme	DECC	The Hydrogen and Fuel Cell Demonstration Programme (HFC), (formerly part of the Hydrogen, Fuel Cells, and Carbon Abatement Technologies Demonstration Programme (HFCCAT),) is supported under the Environmental Transformation Fund (ETF) . The programme - funded by DECC but managed by the Technology Strategy Board - aims to demonstrate components or complete systems in realistic operating conditions. It builds on previous demonstrations under the HFCCAT by enabling successful companies to develop and test the technology in their drive towards commercialisation through further demonstration	The first call for proposals was announced in October 2006. The programme currently supports three projects with funding of £3.7m. A new competition for up to £7.2m of funding was opened in September 2009.		

Table 5.2: Major Demonstration Projects

Name	Description	Sub-topics covered	Total Project Cost	Public Sector Funder	Public Sector Funding	Period
Clean Urban Transport for Europe (CUTE) – London Led to The London Hydrogen bus programme	CUTE Trial : 3 x hydrogen fuel cell bus operated by Transport for London with support from EC as part of wider demonstration in 10 cities Led to : New buses powered by hydrogen fuel joined London's fleet in 2011. They are currently running on route RV1 between Covent Garden and Tower Gateway Station.	Fuel cell bus demonstration Three hydrogen fuelled PEMFC powered buses are operating on commercial routes in London.				Trial from 2003 - 2008 then 2011 onwards
Promoting Unst Renewable Energy (PURE)	Remote power and fuel: 2 x 15 kW Proven wind turbines supplying power to local residents or to electrolyser for hydrogen production and storage (regeneration of electricity through fuel cell or heating/transport)					
London Hydrogen Partnership		The Partnership's principal objective is to work towards the establishment of a hydrogen economy for London and the UK. It aims to: Establish and maintain dialogue among all sectors/actors relevant to the hydrogen economy. Prepare and disseminate relevant materials. Develop the London Hydrogen Action Plan as a route map for				

		clean energy. Provide a platform for funding bids and initiation of projects.				
The Hydrogen Office	The Hydrogen Office energy system includes a 750kW wind turbine, 30kw electrolyser, 10kW hydrogen fuel fell and a geothermal source heat pump. An electric vehicle charging point is the latest addition to the Hydrogen Office. Scottish Enterprise Fife, with support from Scottish Enterprise's Energy Team have developed the Hydrogen Office project in partnership with Alsherra Developments Ltd, and with funding support from European Regional Developments Funds (ERDF).					
Aberdeen hydrogen bus programme	Scottish Government, Scottish Enterprise, Aberdeen council, EU.	Ten hydrogen fuel cell buses to be operating in Aberdeen by 2014.				
UKH2Mobility	A ground breaking Government and industry project to ensure the UK is well positioned for the commercial roll-out of hydrogen fuel cell electric vehicles Initial press release (January 2012) Synopsis of Phase 1 results (February 2013)					

6. Research Facilities and Other Assets

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The main research facilities for hydrogen energy R&D relate to materials investigation. The Science and Technology Facilities Council provides various facilities for new materials investigation using neutrons, X-rays, laser spectroscopy techniques, computational materials science, etc. at its two major sites Rutherford Appleton Laboratory and Daresbury Laboratory and the X-ray diffraction facilities at Diamond.

UK research facilities in the hydrogen storage in solids area are spread among the wide range of academic groups in the UK (see entries above for universities of Bath, Oxford, Nottingham, Birmingham, Glasgow, Newcastle and UCL). Much work in this area relies on chemical synthesis and materials characterisation, much of which is done in-house at various Universities within individual research groups.

Table 6.1: Research Facilities and Assets

Name	Description	Type of asset	Number of supporting staff	Annual Operating Budget
Science and Technology Facilities Council	Neutron spallation source (ISIS) for materials investigation; laser spectroscopy facilities; *in situ* EXAFS; computational materials science			
Diamond and the Research Complex at Harwell	Diamond Light Source is the UK's national synchrotron science facility, located at the Harwell Science and Innovation Campus in Oxfordshire. By accelerating electrons to near light-speed, Diamond generates brilliant beams of light from infra-red to X-rays			
Renewable Hydrogen Research and Development Centre, University of Glamorgan	Electrolytic hydrogen production, compression and storage 21kW peak photovoltaic solar array PEM fuel cell Hydrogen vehicle refueling			

7. Networks

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The Energy Generation & Supply Knowledge Transfer Network (KTN) includes a group for Fuel Cells & Hydrogen.
The UKHFCA (United Kingdom Hydrogen and Fuel Cell Association) was established as a trade association in 2010 (from the merger of Fuel Cells UK and the UK Hydrogen Association), taking over the information dissemination role previously carried out by the now defunct UK Hydrogen Energy Network (H2NET). A similar body exists in Scotland (Scottish Hydrogen and Fuel Cells Association).

In addition, hydrogen plays a role in other networking arrangements specific to transport energy use in the UK. See UKERC Transport Landscape for further information.

Table 7.1 Networks

Network	Date Established	Description	Membership Profile	Activities
H2NET	2000, closed in 2007	Founded in 2000 as an EPSRC Network; part-funded 2003-2007 with support from DTI		Now defunct, web-site of useful resources still maintained
Scottish Hydrogen and Fuel Cells Association	2004		63	
UKHFCA (United Kingdom Hydrogen and Fuel Cell Association)	2010	The UK Hydrogen and Fuel Cell Association acts on behalf of its members to accelerate the commercialization of fuel cell and hydrogen energy technologies. Members include the leading UK fuel cell and hydrogen companies as well as organisations from the academic community and a range of other stakeholders with an interest in these clean energy solutions and the associated elements of the supply chain. The Association was launched in summer 2010 following the merger of Fuel Cells UK and the UK Hydrogen Association.	30	• All fuel cell types and applications; • The full fuel cell supply chain (from research into material science through to systems integration and distribution); • Hydrogen production and storage; • Hydrogen infrastructure; and • Other issues around the delivery, storage and use of associated fuels.
Energy Generation and	2010	The role of the EG&S KTN is to simplify the UK Energy Innovation landscape by		• Provide UK industry and supply chain players with the opportunities to

Supply KTN – Fuel Cells and Hydrogen Group		providing a clear and focused vehicle for the rapid transfer of high-quality information on technologies, markets, funding and partnering opportunities. The result will be an acceleration of developing technologies up the Technology Readiness Level (TRL) ladder.		meet and network with businesses, academia, utilities and other energy innovation stakeholders, and the private investment community, in the UK and internationally • Provide clarity regarding the issues affecting innovative energy technology exploitation at various stages along the innovation pipeline • Enable effective knowledge transfer between all relevant people and organisations, in particular ensuring a match between utility and industrial needs, and supply-chain technology/research capabilities • Encourage the flow of people, knowledge and experience between policy groups, industry, the science base and the utility/generating community, with the common aim of delivering products and services that meet a clear energy need and are commercially attractive • Attract and optimise the various funding sources by use of roadmapping and market analysis • Provide a forum for a coherent industry voice to inform Government policy making and the private investment community • Provide advice on the various support mechanisms (public and private) available to the research base and industry
London Hydrogen Partnership	2002	The Partnership was launched in April 2002 to work towards a hydrogen economy for London and the UK.		• Produce and implement the London Hydrogen Action Plan as a route map for clean energy

				• Establish and maintain dialogue among all sectors/actors relevant to the hydrogen economy • Disseminate relevant materials • Provide a platform for funding bids and initiation of projects
Low Carbon Vehicle Partnership	2002	Created as the result of a recommendation by the Automotive Innovation and Growth Team in 2002.		
Centre of Excellence for Low Carbon Vehicles and Fuel Cells (Cenex)	2005	Cenex is a UK government initiative supported by the Department of Trade and Industry (DTI). It is managed by a small team of full-time staff, supported by secondees for industry. The Cenex management team reports into a Board of Directors consisting of representatives from a core group of member organisations. These members cover the broad cross-section of UK industry interested in low carbon and fuel cell technologies and have played an active role in defining the structure, aims, objectives and priorities for the centre.		

8. UK Participation in EU Framework Programmes

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The European Hydrogen and Fuel Cell Technology Platform was launched under the 6th Framework Programme for Research (FP6) as a grouping of stakeholders, led by companies representing the entire supply chain for fuel cell and hydrogen energy technologies. The Platform concluded that fuel cell and hydrogen technologies can play a significant role in a new, cleaner energy system for Europe. However, if these were to make a significant market penetration in transport and power generation, there would need to be research, development and deployment strategies in which all the stakeholders are committed to common objectives.

Based on this shared vision, The Fuel Cells and Hydrogen Joint Undertaking (FCH JU) was established by a Council Regulation on 30 May 2008 as a public-private partnership between the European Commission, European industry and research organisations to accelerate the development and deployment of fuel cell and hydrogen technologies. An up to date directory of documents and the annually revised implementation plan is maintained.

UK academia and industry has been involved in a wide range of hydrogen (and fuel cell) projects within Framework Programmes 6 and 7 as follows:

Table 8.1: EU Framework Programmes

Project	Objectives	Action Line	Type of Action	UK Participants	Co-ordinator and Partners	Total Funding	EU Funding	Duration	Annual Spend
CACHET II: Carbon dioxide capture and hydrogen production with membranes	CACHET II project will develop innovative metallic membranes and modules for high capacity hydrogen production and separation from a number of fuel sources including natural gas and coal	FP7-ENERGY - ENERGY.2009.5.1.1 Innovative capture techniques	Collaborative project (generic)	BP Exploration Operating Company Ltd	BP Exploration Operating Company Ltd, United Kingdom With 7 Partners	€5.2m	€3.9m	2010-01-01 to 2012-12-31	€1.76m
CHIC Clean Hydrogen in European Cities	The Clean Hydrogen in European Cities (CHIC) Project is the essential next step to full commercialisation of hydrogen powered fuel cell (H2FC) buses.	SP1-JTI-FCH.2009.1.1 Large-scale demonstration of road vehicles and refuelling infrastructure II	Joint Technology Initiatives - Collaborative Project (FCH)	London Bus Services Limited; Air Products PLC; Wrightbus Ltd; Element Energy Limited;	Evobus Gmbh With 25 Partners	€81.9m	€25.9m	2010-04-01 to 2016-12-31	€12.0m
COMETNANO Technologies for synthesis, recycling and combustion of metallic nanoclusters as	COMETNANO project is an integrated approach of metallic-nano-particles synthesis, their controlled combustion in internal combustion engines and regeneration (employing	NMP-2008-1.2-3 Development of technologies for the controlled combustion of nano-particles	Small or medium-scale focused research project	Neo Performance Materials (Europe)Ltd	Centre For Research And Technology, Greece With 4 Partners	€2.4m	€1.7m	2009-05-01 to 2012-04-30	€0.6m

future transportation fuels	100 renewable hydrogen produced by solar-thermal dissociation of water in coated monolithic reactors) of the respective metal-oxides via reduction by renewable means.								
DELIVERHY Optimisation of Transport Solutions for Compressed Hydrogen	Compressed hydrogen trailers are cost efficient for near term distribution. However, with the currently used 20 MPa trailers the supply of larger refuelling stations would result in multiple truck deliveries per day, which is often not acceptable.	SP1-JTI-FCH.2010.2.6 Feasibility of 400b+ CGH2 distribution	Joint Technology Initiatives - Collaborative Project (FCH)	The CCS Global Group Limited, UK	Ludwig-Boelkow-Systemtechnik Gmbh, Germany With 5 Partners	€1.2m	€0.7m	2012-01-01 to 2013-12-31	€1.2m
GREENAIR Generation of Hydrogen by Kerosene Reforming via efficient and low emission new alternative, innovative, refined technologies for aircraft application	GreenAir is addressing one of the key problems for fuel cell application aboard an aircraft - the generation of Hydrogen from Jet fuel (Kerosene) which will be the aeronautic fuel for the next decades	AAT.2008.1.1.4. Systems and Equipment,AAT.2008.4.2.4. Systems	Small or medium-scale focused research project	Johnson Matthey PLC; Qinetiq Limited	EADS Deutschland Gmbh, Germany With 12 Partners	€7.8m	€5.1m	2009-09-01 to 2012-08-31	€2.6m
H2FC Integrating European Infrastructure to support science and development of Hydrogen- and Fuel Cell Technologies towards European Strategy for Sustainable, Competitive and Secure Energy	H2FC brings together, for the first time in Europe, the leading European R&D institutions of the H2 community together with those of the fuel cell community, covering the entire life-cycle of H2FC, i.e. hydrogen production, storage, distribution, and final use in fuel cells. The three pillars of the proposal are networking, transnational access and joint research activities	INFRA-2011-1.1.16. Research Infrastructures for Hydrogen & Fuel Cells facilities	Combination of CP and CSA	University of Ulster; NPL Management Limited; Health and Safety Executive.	Karlsruher Institut für Technologie, Germany With 18 Partners	€10.2m	€8.0m	2011-11-01 to 2015-10-31	€2.5m
H2OCEAN Development of a wind-wave power open-sea platform	The H2OCEAN consortium aims at developing an innovative design for an economically and	OCEAN.2011-1 Multi-use offshore platforms	Collaborative project (generic)	Fusion Marine Limited; Cranfield University;	Meteosim Truewind S.L., Spain With 16 Partners	€6.0m	€4.5m	2012-01-01 to 2014-12-31	€2.0m

equipped for hydrogen generation with support for multiple users of energy	environmentally sustainable multi-use open-sea platform. The H2OCEAN platform will harvest wind and wave power, using part of the energy on-site for multiple applications, and convert on-site the excess energy into hydrogen that can be stored and shipped to shore as green energy carrier.			Viking Fish Farms Limited; IT Power Ltd; Virtualpie Ltd.					
H2SUSBUILD Development of a clean and energy self-sustained building in the vision of integrating H_2 economy with renewable energy sources	The development of an intelligent, self-sustained and zero CO_2 emission hybrid energy system to cover electric power, heating and cooling loads (tri-generation) of either residential/commercial buildings or districts of buildings. In the proposed system, the primary energy will be harvested from RES and directly used to cover contingent loads, while the excess energy will be converted to hydrogen to be used as energy storage material and to be further applied as a green fuel to cover the building heating needs through direct combustion or to produce combined heating and electricity by means of fuel cells	NMP-2007-4.0-5 Resource Efficient and Clean Buildings	Large-scale integrating project	The University of St Andrews;	d Appolonia SPA, Italy With 18 Partners	€9.9m	€6.7m	2008-10-01 to 2012-09-30	€2.5m
HIGH V.LO-CITY Cities speeding up the integration of hydrogen buses in public fleets	By leveraging the experiences of past fuel cell bus projects, implementing technical improvements that increase efficiency and reduce costs of FCH buses, as well as introducing a modular approach to hydrogen refuelling infrastructure build-up, the High V(Flanders).L(Liguria)	SP1-JTI-FCH.2010.1.1 Large-scale demonstration of road vehicles and refuelling infrastructure III	Joint Technology Initiatives - Collaborative Project (FCH)	Aberdeen City Council	Van Hool N.V., Belgium With 11 Partners	€31.6m	€13.5m	2012-01-01 to 2016-12-31	€6.3m

	O(ScOtland)-City project aims at significantly increasing the velocity of integrating these buses on a larger scale in European bus operations.								
HY2SEPS-2 Hybrid Membrane - Pressure Swing Adsorption (PSA) Hydrogen Purification Systems	The main goal of the proposed work is the design and testing of hybrid separation schemes that combine membrane and Pressure Swing Adsorption (PSA) technology for the purification of H_2 from a reformate stream that also contains CO_2, CO, CH_4, and N_2.	SP1-JTI-FCH.2010.2.3 Development of gas purification technologies	Joint Technology Initiatives - Collaborative Project (FCH)	Process Systems Enterprise Ltd	Foundation for Research and Technology, Greece With 4 Partners	€1.6m	€0.8m	2011-11-01 to 2013-10-31	€0.8m
HYCOMP Enhanced Design Requirements and Testing Procedures for Composite Cylinders intended for the Safe Storage of Hydrogen	Hydrogen storage is a key enabling technology for the use of hydrogen as an energy vector. To improve volumetric and gravimetric performance, carbon fibber composite cylinders are currently being developed.	SP1-JTI-FCH.2009.1.5 Pre-normative Research (PNR) on composite storage	Joint Technology Initiatives - Collaborative Project (FCH)	The CCS Global Group Limited	l Air Liquide S.A, France With 11 Partners	€3.9m	€1.4m	2011-01-01 to 2013-12-31	€1.3m
HYCYCLES Materials and components for Hydrogen production by sulphur based thermochemical cycles	HycycleS aims at the qualification and enhancement of materials and components for key steps of thermochemical cycles for solar or nuclear hydrogen generation. The focus of HycycleS is the decomposition of sulphuric acid which is the central step of the sulphur based family of those processes, especially the hybrid sulphur cycle and the sulphur-iodine cycle.	ENERGY-2007-1.2-03 Advanced Materials for High Temperature thermo-chemical processes	Small or medium-scale focused research project	The University of Sheffield	Deutsches Zentrum für Luft - und Raumfahrt EV, Germany With 8 Partners	€5.1m	€3.7m	From 2008-01-01 to 2011-03-31	€1.3m
RELHY Innovative solid oxide electrolyser stacks for efficient and reliable hydrogen	The RelHy project targets the development of novel or improved, low cost materials (and the associated manufacturing process) for their	ENERGY-2007-1.2-01 New materials and processes for advanced electrolysers	Small or medium-scale focused research project	Imperial College of Science, Technology And Medicine	Commissariat à l'Energie Atomique et aux Energies Alternatives, France With 6 Partners	€4.5m	€2.9m	From 2008-01-01 to 2011-12-31	€1.5m

production	integration in efficient and durable components for the next generation of electrolysers based on Solid Oxide Electrolysis Cells (SOEC).								
SOLHYDROMICS Nanodesigned electrochemical converter of solar energy into hydrogen hosting natural enzymes or their mimics	An artificial device will be developed to convert sun energy into H_2 with 10 efficiency by water splitting at ambient temperature.	ENERGY.2008.10.1.1 Future Emerging Technologies (FET)	Collaborative project (generic)	Imperial College of Science, Technology And Medicine	Politecnico Di Torino With 6 Partners	€3.6m	€2.7m	From 2009-01-01 to 2012-06-30	€1.0m
STORHY: Hydrogen Storage Systems for Automotive Application	This IP is a European initiative on automobile H_2 storage driven by major European car manufacturers and covering the full spectrum of currently qualified technologies. Although the primary target of STORHY is the automobile industry, the preparation of spin-offs for stationary systems is also considered.	FP6: SUSTDEV-1.2.2: M-L New technologies for energy carriers Hydrogen	Integrated Project	University of Nottingham	Magna Steyr Fahrzeugtechnik Ag & Co Kg 33 Partners	€18.6m	€10.73m	March 2004 September 2008	€2.68m
NATURALHY: Preparing for the hydrogen economy by using the existing natural gas system as a catalyst	The aim of NATURALHY is to test all critical aspects of a hydrogen system by adding hydrogen to natural gas in existing networks	FP6: SUSTDEV-1.2.2: M-L New technologies for energy carriers Hydrogen	Integrated project	University of Warwick; X/Open Company; Computational Mechanics; PII Limited; Loughborough University; University of Leeds; The Health and Safety Executive; Shellhydrogen; BP Gas Marketing; Transco	N.V. Nederlandse Gasunie 38 Partners	€17.27m	€11.0m	May 2004 May 2009	€2.2m
NESSHY: Novel Efficient Solid	The proposed IP would drive forward the research	FP6: SUSTDEV-1.2.2 New technologies for energy	Integrated Project	University of Salford;	National Center For Scientific Research	€11.61m	€7.5m	January 2006	€1.5m

Storage for HYdrogen	and development of solid storage of hydrogen for vehicle propulsion and associated distribution functions.	carriers Hydrogen		University of Birmingham; Johnson Matthey	"Demokritos" 22 Partners			January 2011	
HYSAFE: Safety of Hydrogen as an Energy Carrier	The objectives of the network include: • To contribute to common understanding and approaches foraddressing hydrogen safety issues; • To integrate experience and knowledge on hydrogen safety inEurope • To integrate and harmonise the fragmented research base; • To provide contributions to EU safety requirements, standards andcodes of practice; • To contribute to an improved technical culture on handlinghydrogen as an energy carrier; • To promote public acceptance of hydrogen technologies.	FP6: SUSTDEV-1.2.2: M-L New technologies for energy carriers Hydrogen	Network of excellence	Building Research Establishment; University of Ulster; Health and Safety Executive	Forschungszentrum Karlsruhe Gmbh 22 Partners	Not Specified	€7.0m	March 2004 March 2009	€1.4m
HYWAYS	Development of a harmonised "European Hydrogen Energy	FP6: SUSTDEV-1.2.2: M-L New technologies for energy carriers Hydrogen	Integrated project	Air Products; Imperial College;	L-B-Systemtechnik Gmbh	€7.92m	€4.0m	April 2004 April 2007	€1.3m

	Roadmap" by a balanced group of partners from industry, European regions and technical and socio-economic scenario and modelling experts			BP Gas Marketing	26 Partners				
ROADS2HYCOM: Research Coordination, assessment, deployment and support to HyCOM	Roads2HyCOM is a project to co-ordinate, assess and monitor research in the field of Hydrogen for stationary and transport power. Its outputs will support planning of future Hydrogen initiatives under FP7 and beyond (known as HyCom), which aim to develop hydrogen communities and stimulate growth in hydrogen technology markets.	FP6: SUSTDEV-AERO-2004-Hydrogen-2 Support of the co-ordination, assessment and monitoring of research to contribute to the definition phase for a hydrogen communities initiative	Integrated Project	Ricardo UK Limited; Air Products PLC; Intelligent Energy Ltd; Element Energy Ltd	Ricardo UK Limited 29 Partners	€7.8m	€4.5m	October 2005 October 2008	€1.5m
HYDROSOL II: Solar Hydrogen via Water Splitting in Advanced Monolithic Reactors for Future Solar Power plants	Building on the results of FP5 project HYDROSOL the present proposal concerns the technical realisation and evaluation of a directly solar heated process for two-step thermo-chemical water splitting using an innovative solar thermochemical reactor as the core of a volumetric receiver	FP6: SUSTDEV-1.2.6 New and advanced concepts in renewable energy technologies Other RES	Specific Targeted Research Project	Johnson Matthey	Centre For Research And Technology Hellas 5 Partners	€4.29m	€2.18m	October 2005 October 2009	€0.545m
HYAPPROVAL: Handbook for Approval of Hydrogen Refuelling Stations	HyApproval is a STREP to develop a Handbook (HB) facilitating the approval of hydrogen refuelling stations (HRS).	FP6: SUSTDEV-1.2.2 New technologies for energy carriers Hydrogen	Specific Targeted Research Project	BP; Air Products; Health and Safety Executive	L-B-Systemtechnik Gmbh 25 Partners	€3.95m	€1.9m	September 2005 September 2007	€0.95m
HYDROGEN: Production and storage of hydrogen	Research on photo-electrochemical hydrogen production and storage in alanates, borohydrides, and a new class of materials based on ammonia	FP6 - Marie Curie	Research Training Network (RTN)	Hydrogen Solar Ltd.; University of Oxford	Universiteit Leiden 10 Partners	€3.54m	€3.54m	September 2006 August 2010	€0.90m
HYTHEC: High Temperature Thermochemical	to evaluate the potential of one thermo chemical process i.e. the Iodine-	FP6: SUSTDEV-1.2.2 New technologies for energy carriers Hydrogen	Specific Targeted Research	University of Sheffield	Commissariat à l'Energie Atomique	€2.94m	€1.9m	April 2004 October 2007	€0.63m

Cycles	Sulphur (IS) cycle and one hybrid cycle i.e. the Westinghouse cycle.		Project		6 Partners				
HYCO: Hydrogen and Fuel Cell ERANET	The goal is to network and integrate national R&D activities in the area of hydrogen and fuel cells. HYCO offers a common platform for information and coordination of programmes and R&D activities at national and regional level; establishes a common knowledge base for a hydrogen economy; and strengthens the European R&D and demonstration infrastructure on hydrogen and fuel cells.	FP6	ERANET	UK did not participate	Forschungszentrum Jülich Projektträger Jülich	€2.70m	€2.70m	Oct 04 Sep 08	€0.68m
HYTRAIN: Hydrogen Storage Research Training Network	The Network funds 10 Early Stage Researchers (PhD students) and 2 Experienced Researchers (Post-Docs) in a carefully integrated project involving specific research projects focussed on the synthesis and performance characterisation of metal hydrides, large-surface area porous adsorbers and hybrid storage systems.	FP6 - Marie Curie	Research Training Network (RTN)	University of Salford; QMUL; University of Strathclyde; University of Nottingham	University of Salford 18 Partners	€2.65m	€2.65m	January 2005 December 2008	€0.70m
INNOHYP-CA: Innovative high temperature routes for Hydrogen Production	Aims to coordinate efforts on the knowledge of hydrogen production technologies and to propose a roadmap for short, medium and long term research programs	FP6: SUSTDEV-2003-1.2.9: M-L Support to the strategic objectives of the programme	Coordinated Action	University of Sheffield	Commissariat à l'Energie Atomique 8 Partners	€0.62m	€0.50m	September 2004 September 2006	€0.25m
COSY: Complex Solid State Reactions for Energy Efficient Hydrogen Storage	Characterization and optimization of novel light weight hydride composites.	FP6 - Marie Curie	Research Training Network (RTN)	University of Oxford (Dr John Sykes)	GKSS Research Centre Gmbh 13 Partners			November 2006 October 2010	

9. International Initiatives

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There is an IEA Implementing Agreements for Hydrogen, with the UK participating in several Tasks. The UK is also a member of the International Partnership for the Hydrogen Economy (IPHE), established on the initiative of the United States in 2004.

Table 9.1: International Activities

Name	Type	Description	UK Contact Point
IEA Hydrogen Implementing Agreement	IEA Implementing Agreement	Task list Active tasks: • Task 20 Hydrogen Safety • Task 21 Biohydrogen • Task 22 Fundamental and Applied Hydrogen Storage Materials Development • Task 23 Small-Scale Reformers for On-Site Hydrogen Supply (SSR for Hydrogen) • Task 24 Wind Energy and Hydrogen Integration • Task 25 High Temperature Production of Hydrogen • Task 26 Water Photolysis • Task 27 Near-Term Market Routes to Hydrogen by Co-Utilization of Biomass as a Renewable Energy Source with Fossil Fuels • Task 28 Large Scale Hydrogen Delivery Infrastructure • Task 30 Global Hydrogen Systems Analysis	Mr. Ray Eaton, DECC
International Partnership for the Hydrogen Economy (IPHE)		The International Partnership for the Hydrogen Economy was established in 2003 as an international institution to accelerate the transition to a hydrogen economy	
The Fuel Cells and Hydrogen Joint Undertaking (FCH JU)	European Union Joint Undertaking	The Fuel Cells and Hydrogen Joint Undertaking (FCH JU) is a unique public private partnership supporting research, technological development and demonstration (RTD) activities in fuel cell and hydrogen energy technologies in Europe. Its aim is to accelerate the market introduction of these technologies, realising their potential as an instrument in achieving a carbon-lean energy system.The three members of the FCH JU are the European Commission, fuel cell and hydrogen industries	

		represented by the NEW Industry Grouping and the research community represented by Research Grouping N.ERGHY.	
Partnership for Advancing the Transition to Hydrogen (PATH)	Association for the promotion of the hydrogen economy (US-based)	The mission of the association is to spread a consensus vision of the hydrogen economy globally and facilitate its implementation.	
International Standards Organisation (ISO)	International standards	ISO standards TC 197 (Hydrogen technologies)	
International Electrotechnical Commission (IEC)	Global organisation	The IEC is the leading global organization that prepares and publishes international standards for all electrical, electronic and related technologies. These serve as a basis for national standardization and as references when drafting international tenders and contracts.Through its members, the IEC promotes international cooperation on all questions of electrotechnical standardization and related matters, such as the assessment of conformity to standards, in the fields of electricity, electronics and related technologies.	IEC National Committee of the United Kingdom, British Electrotechnical Committee, BSI