SUPERGEN DoSH2

Delivery of Sustainable Hydrogen

Future Hydrogen Production Summary Report

18th Oct 2011, Birmingham

Summary of the Event

SUPERGEN DoSH$_2$ consortium hosted an event **'Future Hydrogen Production'** on the 18th October 2011 in Birmingham. The event brought together leading industry stakeholders, policy makers and UK academics working on the next generation of hydrogen production technologies. The event provided an opportunity to discuss the developments and potential business opportunities arising from the SUPERGEN DoSH$_2$ project's research, directly with those academics, as well as the sector more generally.

Speakers including Alastair Rennie (AMEC), Graham Cooley (ITM Power), Robert Evans (CENEX), David Wails (Johnson Matthey), Mark Crowther (GASTEC), Amanda Lyne (ACAL Energy), Natalia Zglobisz (Energy Generation and Supply KTN), Andrew Haslett (Energy Technologies Institute) and Richard Kemp-Harper (Technology Strategy Board) presented their most recent developments. This was also followed by a panel discussion on future hydrogen related R&D funding priorities.

Attendees included leading industrial players such as ; BOC Linde Group, Element Energy, Intelligent Energy, Miba coatings, CPI, HGen Ltd, Advanced Plasma Power, Teer coatings and representatives from academia, DECC, KTN, National Grid, Fuel Cell Today.

The event provided a platform for industry to present their latest developments on the production of hydrogen, fuel cells, and their deployment and associated challenges. International activities (mainly in Germany, USA) and next steps for UK hydrogen landscape were briefly discussed. Finally, ETI discussed the role of hydrogen in the energy supply value chain and Technology Strategy Board provided input on future UK funding for hydrogen and Fuel Cell R&D and demonstration activities.

The presentations made, covered aspects of the following areas: Hydrogen in the energy mix: Is it here, today? and Key challenges in the short, medium and long term for sustainable hydrogen production, storage and deployment.

SUPERGEN DoSH$_2$ Project Consortium

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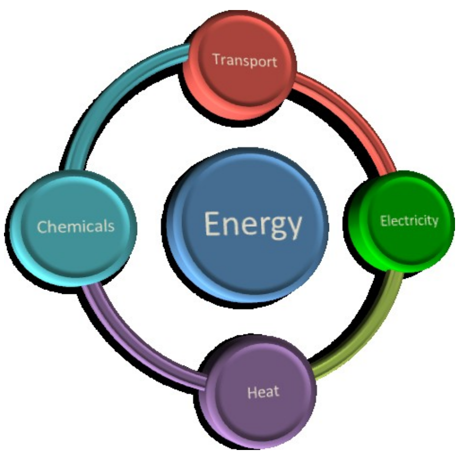
Hydrogen in the energy mix: is it here today?

Hydrogen is widely recognised to have the potential to be able to unlock the capability of clean and renewable energy generation technologies, to address the problems of global warming and energy security[1,2].



Hydrogen, as an energy vector, translates between electricity, heat, transport & chemicals.

Hydrogen, as a unique and versatile energy vector, readily translates between electricity, heat, transport and chemicals and can contribute to addressing the UK's and global future needs for decarbonised supply chains.

Hydrogen enables:

- Time shifting: to match electricity supply and demand by storing hydrogen .
- Sector shifting: to heat, transport and industrial processes
- Low cost transmission via pipeline.

Key areas where hydrogen can demonstrate its impact include:

Addressing intermittency of renewables:
Hydrogen can extend use of renewable or even nuclear electricity baseload generation through storage. Excess power could be utilised for transport or chemicals moving renewable electricity to equally important sectors for CO_2 reduction, i.e. transport and chemicals.

Most renewable energy solutions (e.g. solar, wind) operate on a daily or seasonal cycle, which bears a very modest relationship to daily or seasonal UK/global energy demands. If it is accepted that the energy vectors most likely to be used in 2050 will be electricity, hydrogen, hot water or biogas, the presentation made by Gastec sought to demonstrate that hydrogen may well address this conundrum in the most convenient and low cost fashion[3]. Hydrogen is expected to offer a separation of energy production and demand, thus guaranteeing a market for producers and a supply to users, at times and quantities as required.

De-carbonising transport sector:
Hydrogen fuel cell electric vehicles (FCEV) are based on fuel-cell/battery hybrids, as opposed to the current generation of IC

1. McDowall, W and Eame, M (2006) Forecasts, scenarios, visions, backcasts and roadmaps to the hydrogen economy: A review of the hydrogen futures literature, Energy Policy, 34, 1236-1250. 2. McDowall, W. (2012) Technology roadmaps for transition management: The case of hydrogen energy, technology forecasting and social change.
3. Load balancing in future energy systems, white paper (2011) M E Crowther, GASTEC at CRE Ltd

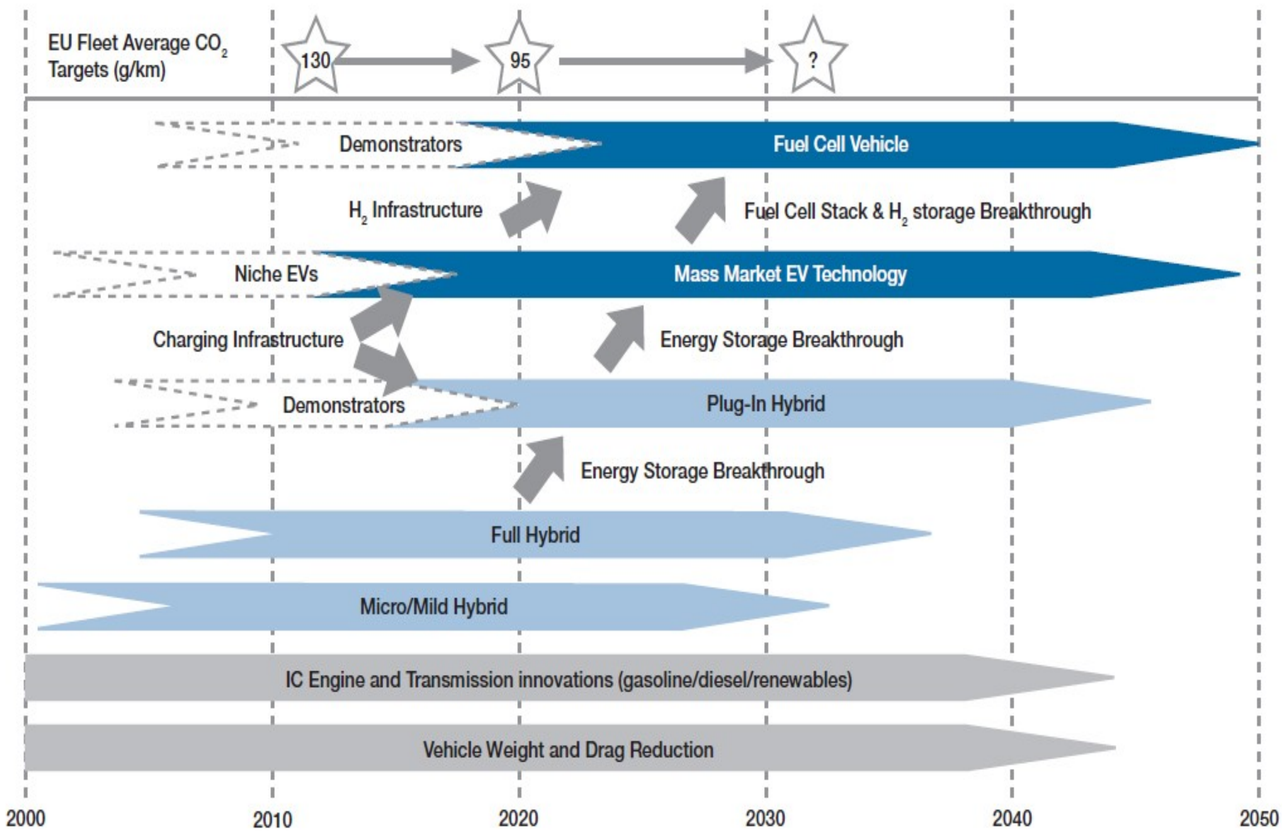
engine/battery hybrids or battery electric vehicles (BEV). They offer zero kerb-side emissions relative to diesel/petrol vehicles, range extension relative to BEV and greater payload relative to BEV but require hydrogen fuel. This can be achieved by distributed hydrogen re-fuellers to offer decentralised, largely self-contained energy systems with enhanced security. If the hydrogen is generated from a zero-carbon renewable (e.g. wind or solar power), the FCEV will have zero carbon emissions as well as zero kerb side emissions.

UK CO_2 reduction targets (80% of 1990 levels by 2050) require a transition from internal combustion engine vehicles to electric and hydrogen fuel cell vehicles utilising ultra low carbon electricity and/or hydrogen.

Fuel cell electric vehicles are seen by the motor industry as particularly promising by virtue of their; high energy efficiency, zero pollutant emissions, ability to run on a decarbonised fuel (hydrogen) and their fast refuel time. Large scale demonstration projects utilising hydrogen fuel cell vehicles are underway and commercially viable technology is ready to go into production (for 2015 launch). FCVs are already available for a selection of vehicles platforms (notably cars and buses).

Fuel cell costs: Government sponsored and private industry research and development continues to reduce fuel cell cost and improve durability and performance. Costs must be further reduced and performance and durability must continue to improve, enabling fuel cells to be fully competitive with incumbent technologies. Speakers at the event discussed that in fact the cost of hydrogen fuel cells have fallen significantly and will very shortly be economical. The fuel cell costs are seen as one of the key steps to commercialisation within the transport sector.

Technology roadmaps: like the one shown below, help to hold together potentially divergent expectations for future technological transitions. In terms of the anticipated timings of shifts in the transport sector from one dominant power-train to another, for which the figure shows that hydrogen and fuel cell technologies are a significant part, this particular roadmap has two key functions. Firstly, it is used as part of the political 'glue' that holds actors and institutions – e.g. governments and the transnational motor manufacturers - together under the banner of a vision of a long-term decarbonised future that includes hydrogen and fuel cells. Secondly, roadmaps are also crucial for evaluating the likely timing forward financial plans in terms of investment in research and development (R&D) and infrastructure.



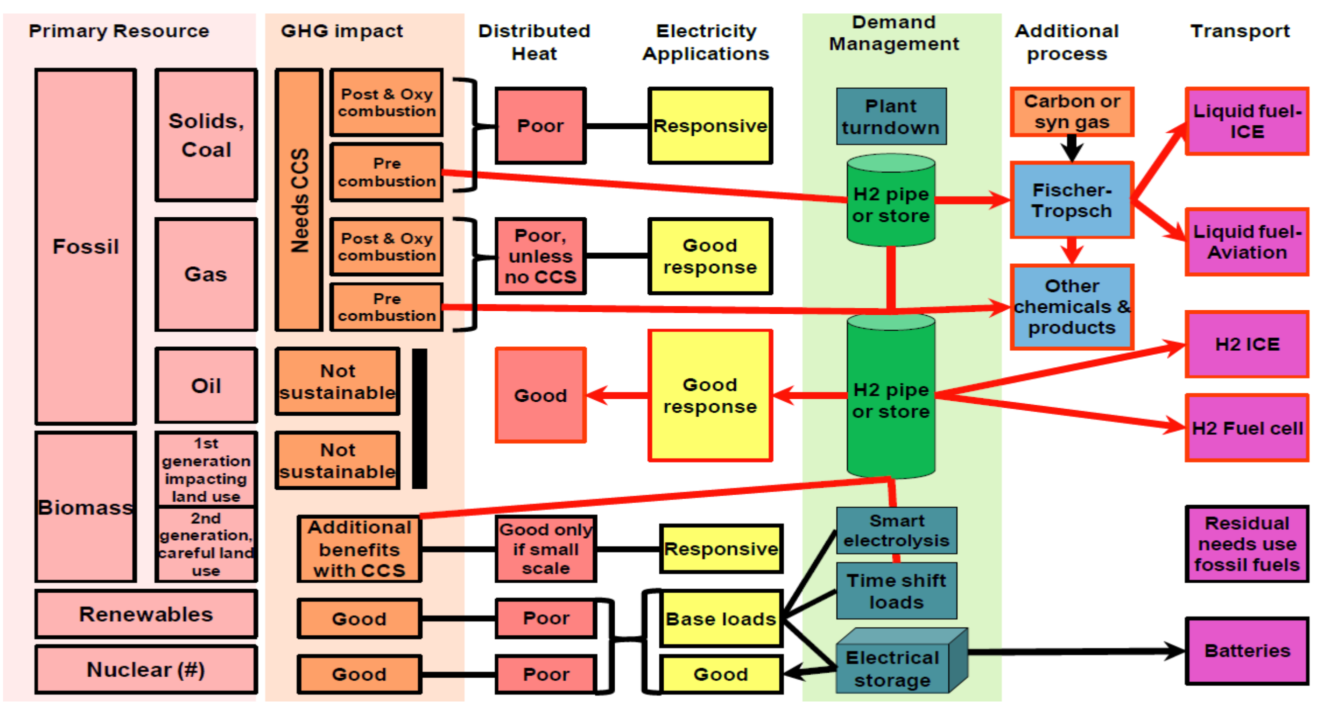
High-level technology roadmap for the UK's decarbonisation of road transport.

Hydrogen and carbon capture and storage (CCS):
CCS converts fossil fuels to low carbon energy. Where CCS uses the pre-combustion, it gasifies and splits hydrocarbons into H_2 and CO_2. The H_2 can be used in power generation, chemical feedstock, transport or heating, either immediately or stored to meet demand. CCS enables hydrogen to be a competitive decarbonised energy vector and chemical if the value placed on CO_2 reduction matches the additional CCS cost.

Hydrogen in the energy mix: where does it fit?
The diagram below illustrates various ways heat, electricity, transport and industrial needs for low carbon energy can be met in the period to 2050 as the UK tackles climate change, diversity of supply, and energy affordability. Given the main known and larger scale technologies, electricity and hydrogen are the main energy vectors, with biogas, methane and oil having roles.

The main sources for hydrogen will be from electrolysis of lower cost electricity and from pre-combustion capture of CO_2. It does appear that CCS will be a competitive way of mitigating climate change by 2020 and to meet sufficient global CO_2 reductions for 2050, it is essential.

The relative amounts of generation capacity from wind, nuclear, and pre-combustion CCS will determine the H_2 volumes available.



Hydrogen in the energy mix (Alastair Rennie, AMEC)

Particularly for H_2 from electrolysis, there will be local niche value for communities rich in renewable resources. Having low carbon H_2 as a large scale, cost competitive intermediate energy vector maximizes asset utilization, use of low cost fossil fuels, and serves power, transport, heat and industrial sectors.

In summary, Hydrogen can contribute to UK's future needs for decarbonised heat, electricity and transport. Following companies that presented at the event are examples of companies developing products to address these markets within the transport and stationary power:

ITM Power:

ITM produces electrolysers, and hydrogen systems based on electrolysers, which offer responsive loads for the electricity sector while providing the transport sector with hydrogen energy storage and refuelling. This hydrogen technology works at the interface between the major energy systems challenges of (i) managing the power system with an increasing amount of renewables and (ii) producing 'green' hydrogen for fuel cell electric vehicles (FCEV). ITM's ongoing Hydrogen On-Site Trial (HOST) is demonstrating this functionality for 350 bar refuelling of return-to-depot van fleets in various commercial settings using the HFuel product. ITM also produces an off-grid electrolyser that is driven entirely by the output of a solar PV array. This is for deployment in highly distributed applications (telecom power and residential zero-carbon homes) so that a source of green hydrogen can be generated at virtually any location.

ACAL Energy:

ACAL Energy has developed a fuel cell power module for a range of uses including stationary, residential and automotive applications requiring larger than 1 kW of power. Their radical and innovative designs are expected to deliver substantial cost savings and performance improvements that will accelerate the adoption of PEM Fuel Cell technologies in key niche markets. Some examples of fuel cell applications in niche markets include:

- Stationary market, with 1-5kW size for telecom back-up in emerging markets and larger size applications are beginning to emerge.
- Materials handling, driven largely by Plug Power, with size range increasing, now up to 20kW.
- CHP applications that are continuing to grow in Japan and German commitment via Callux project .

ACAL also highlighted other global examples for **Stationary deployment** (Hydrogenics Date centre & UPS, Dantherm Power Telecom backup, IdaTech telecom backup (liquid fuel) and Altergy telecom backup), **Fuel cell systems for Combined Heat and Power (CHP)** (UTC SOFC, HEXIS SOFC, BAXI INNOTECH PEM micro CHP, CFCL BlueGen SOFC, EneFarm PEM CHP) and **Fuel cells for materials handling** (PlugPower Gendrive, Hydrogenics, Nuvera).

Gastec at CRE Ltd

Gastec highlighted the need for a low carbon vector such as hydrogen to enable the UK to reduce its carbon reduction commitments in light of the huge variation in seasonal energy demand. They also demonstrated the cost advantages of combining the transport and potential static uses of hydrogen and compared these with electricity[4].

Gastec argued that, if it is accepted that hydrogen is one of the energy vectors most likely to be used in the coming years, it has the potential to offer the most convenient and lowest cost solution. Hydrogen can offer (a) separation of energy and demand (b) lowest cost low carbon fuel vector from fossil fuels with CCS (c) production from electricity at 84% (gross basis) (d) security of supply at low cost (e) a fuel that can be distributed via the UK's existing Low and Medium Pressure (LP and MP) gas distribution network with only modest upgrades, at low cost , with the potential of regional or sub-regional production (f) micro Combined Heat and Power (mCHP) via the most proven fuel cell technologies, all at low capital and operating costs compared to electricity, hot water or biogas.

Gastec also highlighted the issues around intermittency of UK wind production, UK average and peak instantaneous demand, current and future gas, oil and electrical consumption and its implications on overall future energy demand and supply. Hydrogen end use options were discussed, with a primary assumption that within buildings, hydrogen would be the boiler/burner replacement fuel, in combination with the hydrogen fuel cells being developed for stationary power production.

Gastec also shared their author's views on building a series of hydrogen production facilities around the country to feed into the existing medium and high pressure natural gas grid, augmented by local hydrogen storage facilities and allowing the local grid to convert natural gas to hydrogen. The production plants could be either fossil fuel with CCS or renewable/nuclear based.

4. Load balancing in future energy systems, white paper (2011) M E Crowther, GASTEC at CRE Ltd

Key challenges for penetration of hydrogen within the energy mix.

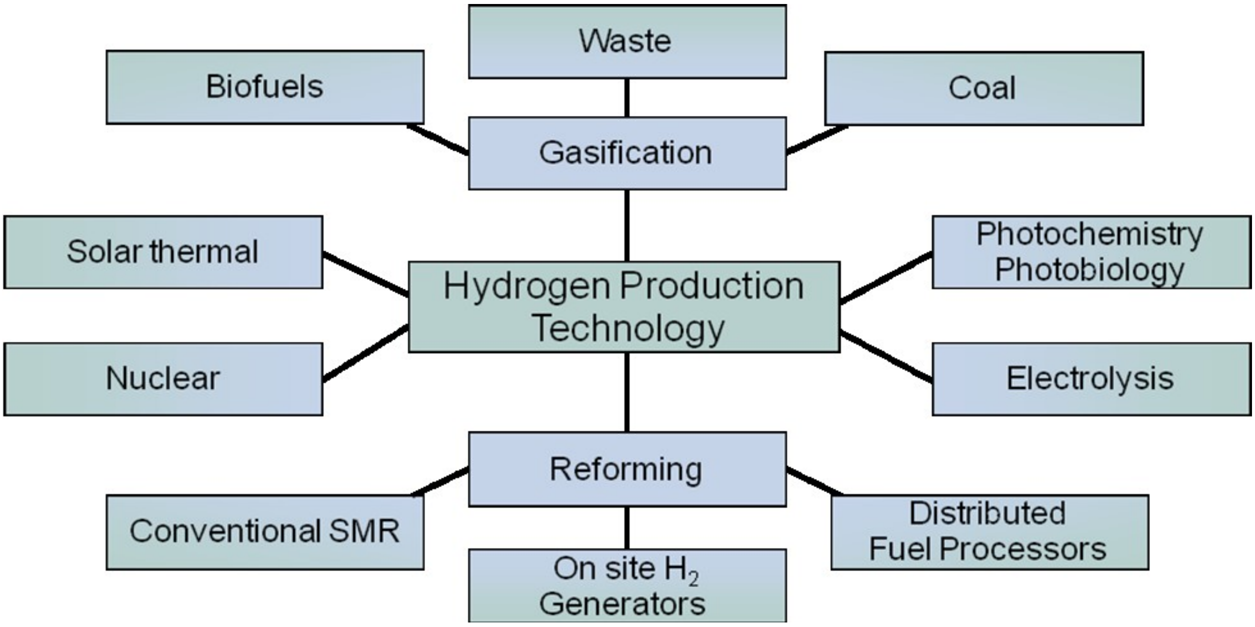
The challenges in enabling a better penetration of hydrogen within the energy mix, relate to both technical and commercial issues including (i) Sustainable production of hydrogen and storage (ii) Distribution, from production to point-of-use (iii) Adoption by end-users and consumers and (iv) Costs associated and relative advantages.

The speakers presented their thoughts relating to the challenges in production and storage and penetration into applications in transport and power balancing.

Challenges in sustainable hydrogen production and storage: David Wails from Johnson Matthey discussed a number of routes to hydrogen production that are either in current use or in development, as illustrated in the diagram below. On an industrial scale, most hydrogen is currently manufactured via steam methane reforming (SMR). This SMR unit is generally integrated into the plant, utilising hydrogen, particularly for ammonia and methanol production and the application of hydrogen in transportation fuel hydrodesulphurisation. Within these sectors, there is usually little excess hydrogen produced that is available for other applications. Other routes to hydrogen include electrolysis and gasification. Sustainable feedstock for gasification include waste, biomass and biofuels, however where significant coal reserves are available (USA, China) coal gasification (possibly including CCS integration) for hydrogen production is likely to be an increasingly important source of hydrogen.

Other sustainable sources of hydrogen include indirect renewables (e.g. the storage of renewable electricity through electrolysis) and direct renewables such as photocatalysis, biogenicH2, and high temp solar water splitting.

Where hydrogen is required on a smaller scale (such as for fuel cell vehicle refuelling), manufacture can be either via traditional SMR routes (tonnes per day) and then transported, or hydrogen production carried out on site. In recent years, a number of platinum based catalysts have been developed to replace the traditional nickel based reforming catalysts. Advantages with these new catalysts include; tolerance to start up and shutdown in air, compactness and their ability to reform non methane fuels including gasoline, diesel and biofuels. The current major disadvantage is cost. They are typically used in small scale (litres of hydrogen per day) applications such as residential CHP, power back-up and on-board vehicle hydrogen production (for either fuel cells, combustion enhancement or emission control). Depending on the scale of on-site hydrogen production and the fuels available, either scaling down conventional SMR or scaling up new reforming technology could be possible.



Sources for hydrogen production

For sustainable hydrogen production via reforming, the key challenge is efficient hydrocarbon processing, utilising sources including; biofuels, waste, biomass, biogas, and emerging hydrocarbon sources (e.g. waste glycerol from biodiesel production). Requirements for this include both new processes and new catalysts for existing processes. Integration with carbon capture and storage is also a key challenge.

The utilisation of alternative (non-methane) hydrocarbon sources presents additional challenges in the area of purification, including; hydrocarbon clean-up, effective reformate desulphurisation, and non-pyrophoric CO-removal. Detailed understanding of the chemical composition of these hydrocarbon sources is essential to their successful utilisation.

For centralised or on-site hydrogen production, distribution, compression and storage also need to be addressed. Hydrogen storage is a key priority area; storage materials R&D will shape the infrastructure deployment for future of production, distribution and use. Challenges include the next big idea in solid state H_2 storage and storage optimisation for the end application (packaging, heat integration). Options for large scale storage options also need addressing – these could include organic carriers, hydrocarbons and slurries. Hydrogen storage and re-fuelling infrastructure remains a key challenge for the achievement of mass market uptake of fuel cells.

Furthermore, challenges in distribution, from production to point-of-use were mentioned. Issues around re-fuelling infrastructure based on centralised versus localised production for automotive & transport applications, for niche application (packed gas logistics) are receiving considerable attention by industry involved in the supply chain. Market development for hydrogen fuel cell vehicles depends on cost effective fuel cell vehicle offerings to the market, which in turn depends on cost effective hydrogen supply.

For fuel cell vehicles, the unique technology needs are compact and cost effective onboard hydrogen storage and high performance, high durability, low cost fuel cell stack technology. Current onboard hydrogen storage technologies don't yet deliver against industry performance (energy density by volume and mass) targets (e.g. US Department of Energy targets), whilst the motor industry continues to invest in research to boost performance and cut costs for fuel cell stack technology to target cost levels that will be cost competitive (with other power trains) in mass production (100,000s of units per annum).

Finally, several factors known to influence adoption by end-users and consumers were mentioned, such as increased awareness, risk factors perception, cost versus environmental benefits and relative performance benefits.

Appendix A

Future Hydrogen Production ; Agenda
8th October 2011: Macdonald Burlington Hotel, Birmingham

09:00	Arrival and Registration
09:30	Welcome and Introduction Dr Martin Smith, Project Manager, St Andrews University
09:35	The UK's Hydrogen Future Alastair Rennie, Project Director for Renewables at AMEC
09:50	Challenges in Sustainable Hydrogen Production Dr David Wails, Principal Scientist, Johnson Matthey
10:05	Achievements of the SUPERGEN DoSH_2 Project Professor John Irvine, Project Coordinator and St. Andrews
10:25	Comfort Break and Networking
	Session 1: Hydrogen for Transport
10:45	Hydrogen for Transport Robert Evans, CEO of Cenex
11:05	Hydrogen as Energy Storage and Clean Fuel Dr Graham Cooley, CEO of ITM Power
11:25	Poster Session 1
12:15	**Lunch and Networking**
	Session 2: Hydrogen for Energy Storage, Load Balancing and Managing Intermittency
13:00	Hydrogen for grid-2-gas load balancing in future energy systems Mark Crowther, General Manager at GASTEC
13:20	Hydrogen for Energy – Pure and Sustainable Amanda Lyne, ACAL Energy, VP Strategic Business Development
13:40	Poster Session 2
14:30	Comfort Break and Networking
	Session 3: UK Strategy for Hydrogen: Funding and Policy
15:00	Fuel Cells and Hydrogen Programme at the Technology Strategy Board Dr Richard Kemp-Harper, Lead Technologist at Technology Strategy Board
15:20	Hydrogen as a key energy vector in robust UK energy system designs Andrew Haslett, Director of Strategy Development for the Energy Technologies Institute
15:40	Energy Generation and Supply KTN – benefiting from engagement Natalia Zglobisz, Energy Generation and Supply KTN
16:00	Hydrogen Research and Funding Priorities Panel Discussion- Chaired by Professor John Irvine
16:30	Closing remarks - Dr Martin Smith,

Appendix B

Future Hydrogen Production; List of Attendees
8th October 2011: Macdonald Burlington Hotel, Birmingham

Andrew Allan	**MSc Environmental Management**
David Book	**Reader in Energy Materials, *Birmingham University***
Waldemar Bujalski	**Senior Research Fellow, *Birmingham University***
Lino Carta	***Cardiff University***
Graham Cooley,	**CEO, *ITM Power***
Mark Crowther	**General Manager, *GASTEC***
Michael Dolman	**Consultant, *Element Energy***
Charles Dore	**Key Account Manager Technology & Research, *Air Liquide***
Valerie Dupont	**Reader, *Leeds University***
Ray Eaton	**Assistant Director, Fuel Cells & Hydrogen, *DECC***
Malcolm Eaves	**Research Chair, *Low Carbon Research Institute (LCRI)***
Robert Evans	**CEO, *Cenex***
Emma Farndon	**Senior Research Engineer, *Intelligent Energy***
Sue Field	**Senior Researcher, *Miba Coatings Group***
Francisco R. Garcia Garcia	**Imperial University**
Nikos Giannakeas	**PhD Student, *Leeds University***
Lindsay Gill	**Communications Executive, *Centre for Process Innovation***
Shak Gohir	**Practice Director, *Centre for Process Innovation***
Celia Greaves	**Lead: Fuel Cells and Hydrogen, *Centre for Process Innovation***
Nick Hacking	**Researcher, *Low Carbon Research Institute***
Arun Harish	**Commercialisation Manager, *Centre for Process Innovation***
Rex Harris	***Birmingham University***
Andrew Haslett	**Director of Strategy Development, *Energy Technologies Institute***
Gary Hayes MD	**Owner, *HGEN LTD***
Jon Helliwell	**EU Bids Manager, PETEC, *Centre for Process Innovation***
Sam Hoare	**Business Development Advisor, *G & H Associates Limited***
John T.S. Irvine	**SUPERGEN DoSH2 Project Coordinator, *St Andrews University***
Simon James	**Market Specialist, *Air Liquide***
Richard Kemp Harper	**Lead Technologist, *Technology Strategy Board***
Mahdi Kiaee	**PhD Research Student, *University of Strathclyde***
Hiren R Kotadia	**Researcher, *King's College London***
Kang Li	***Imperial University***
K M Kerry Yu	**PDRA, *Oxford University***
Stephen Marland	**Future Projects & Innovation Manager, *National Grid***
Neil McKeown	***Cardiff University***
Ian S. Metcalfe	**Professor of Chemical Engineering , *Newcastle University***
Roger Molinde	**PhD Student, *Leeds University***

Shahrouz Nayebossadri	***Birmingham University***
Lydia Pickering	***Birmingham University***
Bruno G. Pollet	**Associate Director, *Centre for Hydrogen & Fuel Cell Research, University of Birmingham***
Noor Quadri	***St Andrews University***
Mark Randle	**Relationship Manager, *ETDE Contracting Ltd***
Alastair Rennie	**Project Director for Renewables, *AMEC***
Martin J. Smith	**SUPERGEN DoSH2 Project Manager, *St Andrews University***
Colin Stewart	**Business Development Manager, Innovation, *BOC***
Richard Taylor	**Technical Director, *Advanced Plasma Power Limited***
Xiaoling Teer	**Senior Researcher, *Teer Coatings Ltd***
Alan Thursfield	**Research Associate, *Newcastle University***
Rumen Tomov	**Research Associate, *University of Cambridge***
Xin Tu	**Postdoctoral Research Associate, *Manchester University***
David Wails	**Principal Scientist, *Johnson Matthey PLC***
Martin Wills	***Warwick University***
Jonathan Wing	**Market Analyst *Fuel Cell Today***
Natalia Zglobisz	***Energy Generation & Supply KTN***

Appendix C

Future Hydrogen Production ; Presentations
8th October 2011: Macdonald Burlington Hotel, Birmingham

Presentations from the event are available at:
http://supergendosh2.wordpress.com

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www.supergen14.org

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