Hydrogen research

Presentation to
Research Focus Workshop on Green Car Technologies
16 Nov 2009

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RE/fossil fuel/nuclear paths to H$_2$
Renewable Paths to Hydrogen

Renewable Energy

Heat

Mechanical Energy

Electrolysis

Thermolysis

Electricity

Conversion

Biomass

Photolysis

Hydrogen
In 2003 the Bush administration appeared to have made the strategic decision to shift over the coming decades to hydrogen as the main fuel for transportation.

“Tonight, I’m proposing $1.2 billion in research funding so that America can lead the world in developing clean, hydrogen-powered automobiles…

…and so that the first car driven by a child born today could be powered by hydrogen, and pollution-free.”

*President’s State of the Union Address January 28, 2003*
The timeframe is long and the investment is large to develop a hydrogen and transportation market that reduces our Nation's dependence on foreign sources of energy while minimizing environmental impacts.

US DoE Hydrogen Posture Plan 2006

- Hydrogen produced from diverse, domestic resources at $2.00-$3.00 per gallon [$A 0.4 – 0.6 /litre] of gasoline equivalent (delivered, untaxed)
- On-board hydrogen storage systems with improved capacity to enable a driving range greater than 300 miles [480 km] for most light-duty vehicles
- PEM automotive fuel cells that cost $30-$45 per kilowatt and deliver 5,000 hours of service (service life of vehicle)

NB. Auto petrol engines typically $US 25-35/kW.

Fuel cells

• 3M has developed membrane electrode assembly to extend durability in the lab to over 7,300 hours with voltage cycling (> DOE 2010 target of 5,000 hours in an automotive fuel cell system)
• Alloy catalyst used for this MEA is approaching the 2010 target for total platinum content (g/kW)
• Cost reduction for 80-kW fuel cell systems from $94/kW in 2007 to $73/kW, projected to high-volume manufacturing (500,000 systems/year). Target $30/kW.
Renewable-energy hydrogen production

- NREL and OSU bio-oil/ethanol steam reforming processes have potential to meet the 2019 hydrogen production cost target of $3.00/gasoline gallon equivalent (gge) including delivery.
- Giner Electrochemical Systems, LLC has improved electrolyser stack efficiency from 61% to 74%.

Storage

- HRL Laboratories and Lawrence Livermore National Laboratory have incorporated hydrogen storage materials, such as LiBH4, into carbon aerogel scaffolds to attain 12.5 wt% at 300°C (well above DoE target)
Latest US Government moves on H2

• Early 2009, President Obama /Energy Secretary Geoffrey Chu cut funding for H2 fuel program from $169 m to $68 m for 2010, concentrating on hybrids and battery-electric vehicles

• But July 2009, US Senate approved $190 m for H2 program, an increase on earlier amount
Hydrogen Technology Roadmap - Australia

• Released in November 2008
Vision for hydrogen and fuel cells in Australia:

By 2020 Australia is effectively exploiting emerging hydrogen and fuel cell market and supply-chain opportunities, locally and globally.
Hydrogen Technology Roadmap: recommendations

Building on and extending R&D capability on hydrogen and fuel cells important, but top five priorities should be:

- Large-scale demonstration projects, to pull and underpin R&D; technology, industry and policy development; regulations, codes and standards; and overseas interest in Australia as a market.
- Establishment of an advocacy group in Australia (the proposed hydrogen and fuel cell industry association) which is comprehensive and widely supported – for education and outreach, particularly to end-users and project/venture financiers.
- Accelerated development of regulations, codes and standards in Australia that facilitate the market uptake of non-industrial hydrogen
- Use of fuel cell products.
- Systems analysis modelling, including further cost modelling and comparative analysis
- Public policy that both pulls and pushes progress in hydrogen and fuel cells, particularly pricing carbon emissions and government purchasing policies
HONDA FCX Clarity hydrogen car

- Unveiled 02/07/08 in Tokyo
- Available for lease from Nov 2008
- Compact lightweight Honda V Flow PEM fuel cell stack (100 kW)
- Range 620 km
- Low-volume commercial production has begun
- Selling in Japan and US a few dozen units a year and about 200 units within three years.
- Hollywood stars are among the first customers: e.g. Jamie Lee Curtis and her husband Christopher Guest, actress Laura Harris, film producer Ron Yerxa.
## HONDA FCX Clarity specifications

<table>
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<th>Power train</th>
<th>Description</th>
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<td>Number of occupants</td>
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<tr>
<td><strong>Motor</strong></td>
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<tr>
<td>Max. output</td>
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<tr>
<td>Max. torque</td>
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<tr>
<td>Type</td>
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<td><strong>Fuel cell stack</strong></td>
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<tr>
<td>Type</td>
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<td>Max. output</td>
<td>100kW</td>
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<td>Voltage</td>
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<td><strong>Fuel</strong></td>
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<td>Tank capacity</td>
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<td>Dimensions (L × W × H)</td>
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<td>Vehicle weight</td>
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<tr>
<td>Maximum speed</td>
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<td>Energy storage</td>
<td>Lithium ion battery</td>
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FORD Focus FCV

- Ballard 902 PEM Fuel Cell stack
- 350 bar pressurized hydrogen tank
- Range 240 – 320 km
Hydrogen FC vs battery electric cars?

• Electricity to produce H2 and charge batteries must come from renewable sources to achieve zero-emissions.
• H2 storage particularly in solid-state metal hydrides can give much greater range, and lower mass+vol in car.
• Production of H2 from solar/wind/wave power allows longer-term storage (season to season) and hence continuity of supply.
• Short-term roundtrip energy efficiency of H2 route is lower than batteries, but longer term (>a few weeks) is superior.
• H2 can be produced directly from 2nd generation biomass (trees, algae, other non-food biomass) not just using electricity and electrolysis of water.
Combination of H2 FC and small battery may be optimal

• As in Honda FCV
• Utilises short-term storage advantages of battery over H2, with H2 used for longer term storage
• Overcomes range limitation of battery-electric
• Battery allows regenerative braking
SAMME RENEWABLE-ENERGY HYDROGEN R&D PROGRAM

- RE H2 systems for standalone, remote, back-up and uninterruptible power supply markets
  - Member of CSIRO National Hydrogen Materials Alliance
  - Also collaborating with CSIRO Energy Technology Hydrogen R&D group
  - ARC Linkage application with Telstra
- Hydrogen ICE racing car (with Ingolstadt University of Applied Sciences)
Cluster project 6

INTEGRATION OF ELECTROLYSER, HYDROGEN STORAGE AND UTILISATION SYSTEMS:
CSIRO Hydrogen Materials Alliance
Final Workshop

Project leader: Dr John Andrews
School of Aerospace, Mechanical and Manufacturing Engineering
RMIT University
Goal

• More energy-efficient and economically competitive systems for production of hydrogen by electrolysis from solar and wind energy sources, and utilisation for electricity generation and heat

• Same work also very relevant to production of hydrogen from renewables for transport
Optimal coupling of photovoltaic panels with PEM electrolysers in solar/wind hydrogen systems for remote power supply

Biddyut Paul
Completed PhD project
Conventional and direct coupling of PV array and electrolyser

Conventional coupling of PV-PEM electrolyser

Direct coupling of PV-PEM electrolyser
Characteristics of PV Panel

Current – Voltage relationship of a PV:

\[ I = n_p I_{ph} - n_p I_r e^{\left(\frac{q V}{A k T n_s}\right)} - 1 \]

At maximum power point:

\[ e^{\left(\frac{q V_{max}}{k T A n_s}\right)} \times \left[\frac{q V_{max}}{k T A n_s}\right] + 1 = \frac{I_{ph} + I_r}{I_r} \]

Simulated I-V characteristics curve of BP 275 (75 W) solar panel showing maximum power point (MPP) line
Matching of maximum power point line of a PV module with current-voltage characteristic curve of a PEM electrolyser by changing the series-parallel stacking configuration in both the PV module and electrolyser.
Series—parallel stacking of PV panels and PEM electrolyzers

PV array

Electrolyser bank
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<th>PV- electrolyser combination</th>
<th>Annual energy loss △E kWh</th>
<th>Annual energy loss △E %</th>
<th>Annual hydrogen production (g)</th>
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Direct coupling of RMIT 2.4 kW PV array with CSIRO 2 kW PEM electrolyser

2.4 kW roof mounted PV array at RMIT Bundoora East

2 kW PEM Electrolyser (Oreion Alpha 1)
Optimal coupling of wind turbines and PEM electrolysers

Akraphon Janon
PhD Student – thesis under examination
Unitised Regenerative Fuel Cells

Dr Arun Doddathimmaiah completed PhD project
A schematic of a unitised regenerative fuel cell system (URFC)
URFCs: main technical challenges

- Design of bifunctional oxygen electrodes
- Increasing roundtrip energy efficiency
- Extending lifetime
- Stack design
- URFC energy storage system design
- Lowering unit costs
Estimated roundtrip energy efficiencies at maximum power input and output of experimental URFCs reviewed.
New theoretical model of URFC

- Covers both electrolyser (E) and fuel cell (FC) mode operation
- Based on Butler-Volmer equations for both hydrogen and oxygen electrodes
- Additional terms based on logistic function to incorporate saturation effects at high current densities in both modes
- Includes impacts on cell potential of membrane proton conductivity, internal resistance, and electrical conductivity of endplates and gas diffusion backing layers
Oxygen electrode

\[
j^O_{cell} = j^O_o \frac{\exp \left( \eta^O \alpha^O 2F \right) - \exp \left( -\frac{\eta^O (1 - \alpha^O) 2F}{RT} \right)}{\exp \left( \frac{\eta^O \alpha^O 2F}{RT} \right) + \exp \left( -\frac{\eta^O (1 - \alpha^O) 2F}{RT} \right)} \left( \frac{J^E_{sat}}{j^O_o} \right) - \exp \left( \frac{\eta^O (1 - \alpha^O) 2F}{RT} \right) \left( \frac{J^{FC}_{sat}}{j^O_o} \right)
\]

Hydrogen electrode

\[
j^H_{cell} = j^H_o \frac{-\exp \left( -\frac{\eta^H \alpha^H 2F}{RT} \right) + \exp \left( \frac{\eta^H (1 - \alpha^H) 2F}{RT} \right)}{\exp \left( \frac{-\eta^H \alpha^H 2F}{RT} \right) + \exp \left( \frac{\eta^H (1 - \alpha^H) 2F}{RT} \right)} \left( \frac{J^E_{sat}}{j^H_o} \right) + \exp \left( \frac{\eta^H (1 - \alpha^H) 2F}{RT} \right) \left( \frac{J^{FC}_{sat}}{j^H_o} \right)
\]

Use same equations for both modes by changing signs of overpotentials (\(\eta^O\) and \(\eta^H\)) and hence current densities between modes.
Experimental tests

Measured URFC polarisation curves for MEAs with 2-4 mg/cm² Pt loading on H-side and various catalyst loading on O-side.
Solar-hydrogen Combined Heat and Power (CHP) system
Bahman Shabani
PhD student – CSIRO scholarship
Solar-hydrogen CHP system

- Utilising the heat from the fuel cell as well the electricity can increase the cell’s overall energy efficiency from ~30-55% for electricity generation only, to ~60-80% for heat and power generation
500 W PEM fuel cell experimental rig

- Hydrogen sensor
- Safety interlock control box
- Experimental rig in the fume cupboard
- Pressure sensor to report the function of the fan to the safety interlock system
- These power outlets are interlocked with extraction fan and hydrogen sensors. The 24 V AC to DC converter is supplied from these outlets
- 24 V DC supply to the hydrogen solenoid supply valve system

Diagram:
- Flow meter
- Hot water
- Cold cooling water
- Water tank used for filling the cooling system with water
- Normally-dosed valve has to be opened fully while the pumps are working to remove the air bubbles from the system
- Water pump
- Flow control valve
Opportunities
RMIT-UNSW-Telstra ARC Linkage application

• Solar hydrogen energy systems for highly-reliable and unattended power supply to remote telecommunication facilities
Solar-wind hydrogen fuelling station
Solar-wind hydrogen fuelling station

- Demonstration in Victoria/Australia
- Linked strands of R&D (following up research lines established for RAPS)
- Application to Vic Science Agenda Investment Fund (unsuccessful) – looking for new opportunity
- Source of H2 for demonstration hydrogen FC and ICE cars
Wave energy – hydrogen system

- Wave power resources off SW facing coastlines of Australia are very good
- Large-scale potential for production of hydrogen by electrolysis of sea water for transport applications
- SAMME pre-feasibility study nearing completion
Hydrogen ICE racing car

- RMIT University’s hydrogen-fuelled racing car, has been built in partnership with Ingolstadt University of Applied Sciences, to be entered in the international competition, “Formula H”, for hydrogen cars designed and built by universities around the world. This car was launched at Federation Square, Melbourne, in November 2008.