# "From Research to Reality" Achieving the mass commercialization of Hydrogen FCVs by 2020

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Global Vice President,
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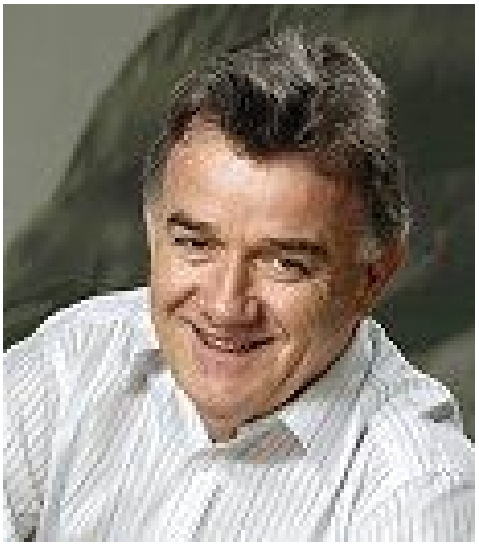
Clean Technology Conference 2008,
Boston, Massachusetts, USA
3rd June 2008



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In January 2006 Duncan Macleod became Vice President in charge of Shell Hydrogen, a Shell business created in 1999 to develop hydrogen as a future fuel for mobility and power. Duncan has a Shell career spanning three decades working in Venezuela, the Caribbean, Nigeria, Japan and the Netherlands and has held key positions in supply/trading, M&A, Upstream, Strategy, Government Relations. Duncan was also instrumental in setting-up Shell's biofuels technology ventures with Iogen in Canada and Choren in Germany.

Duncan is also a member of the Advisory Council for the EU Hydrogen & Fuel Cell Technology Platform, the California Hydrogen Highway Network Advisory Panel and The California Fuel Cell Partnership Steering Team. His personal vision is that for Shell to be successful for another 100 years, substantial new energy businesses such as hydrogen must be developed now, steadily building on Shell's many capabilities while collaborating with Governments, industry partners and customers.

Duncan is Scottish-born, studied Economics & Geography at Birmingham University, is married with three daughters and has interests including photography, art, music and diving.

### *Executive Summary*

What will it take to achieve mass commercialisation of FCVs by 2020? Will zero emission fuels really come soon enough? And how can hydrogen, dubbed as a 'miracle fuel' reduce air pollutants and greenhouse gas emissions, improve air quality and protect against climate change.

One man with most of the answers is Duncan Macleod, Shell Hydrogen's Vice-President. In his latest speech Duncan gives a keynote address to a 'sustainable technology' audience at the Clean Technology Conference in 2008 in Boston to talk about hydrogen and the contribution it can make to clean future fuel transportation.

In meeting increasing demand for energy in the future, Duncan discusses how a portfolio of solutions is needed to tackle climate change, and the role of hydrogen for power generation; as a fuel; and for fuel cell application, as the only pure CO2 free drivetrain.

Duncan also discusses the challenges of bringing FCVs onto the roads, and how industry needs to ramp up activity and bridge the gap between current demonstration projects and full infrastructure roll out to achieve its 2020 goal.

With Hydrogen now standing at a pivotal juncture, with investment rising, costs falling, and technology continuing apace, Duncan also shares Shell's experiences of testing FCVs in real-life conditions and investment the company is making to develop clean/green hydrogen.

With clean, green hydrogen on its way, and 2020 still over a decade away, Duncan also shares his views on the near term, and how the electric mobility revolution is helping to plug the time gap until industry is ready for the mass roll out of FCVs..

***Introduction***

Ladies and Gentlemen, Good Morning! It is a privilege to be here and be part of such a broad – and increasingly influential – movement on sustainable technology. Indeed, given the stark warnings issued by the Intergovenmental Panel on Climate Change, the need to move rapidly from research to reality is now more important than ever.

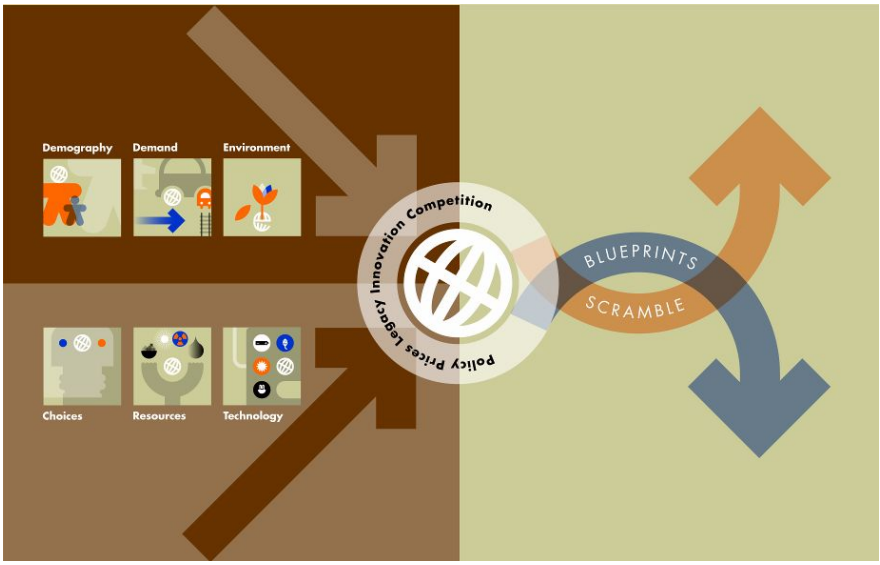
Yet we face an undoubted dilemma: how do we meet the ever increasing demand for energy…while living in an increasingly carbon-constrained world? Because at Shell, there are three hard truths we have come to appreciate:

1) With population growth and economic development, energy demand *will* increase dramatically – in fact doubling by 2050, according to the International Energy Agency;
2) After 2015, easily accessible supplies of oil and gas will simply *not* be able to keep up with it; and
3) We will have no choice *but* to add other sources of energy – Renewables, yes, but also unconventional fossil fuels, such as oil sands. Yet using more energy inevitably means emitting more $CO_2$…

Just to bring this home a little, in the US alone, vehicles consume eight million barrels of oil every day[1] and by 2030, overall energy demand is expected to increase by a massive 19%[2]. So even if we ramp up the production of biofuels, Gas to Liquids and unconventional fossil fuels, meeting this demand is *not* a foregone conclusion.

So, is there any way we can provide some order into the chaos?

Of course, no one can predict the future. Yet we know the different pieces of the jigsaw and that they could come together in different ways, to create different pictures. At Shell, we call these global energy scenarios.




And our latest are particularly interesting – not just because of the dramatic developments they describe; but because, for the very first time, Shell has expressed a preference for one over the other.

One thing, however, is certain: by 2100, the world's energy system will be radically different from today's. Renewables will make up a large part of it and humans will have found ways to deal with air pollution and GHG emissions. Energy efficiency will also have improved significantly.

That's the good news…but how will we get there?

[1] State Energy Office

[2] API

### *Shell Global Energy Scenarios: which road will we take?*

In the first scenario – which we call Scramble – nations rush to secure energy resources, fearing that energy security is a zero-sum game, with clear winners and losers. The use of local coal and home-grown biofuels increases fast. Regulation is geographically fragmented and major developing countries remain outside climate change agreements. The result? A high carbon intensity path – well above 550 ppmv.

The alternative scenario? We call this Blueprints and it is less painful, even if the start is more disorderly. It shows numerous coalitions meeting the challenges of energy security and pollution through cross-border cooperation. The result? A market-based emissions pricing and trading system that is geographically dispersed…but which succeeds in stabilising $CO_2$ emissions at 450-550 ppmv.

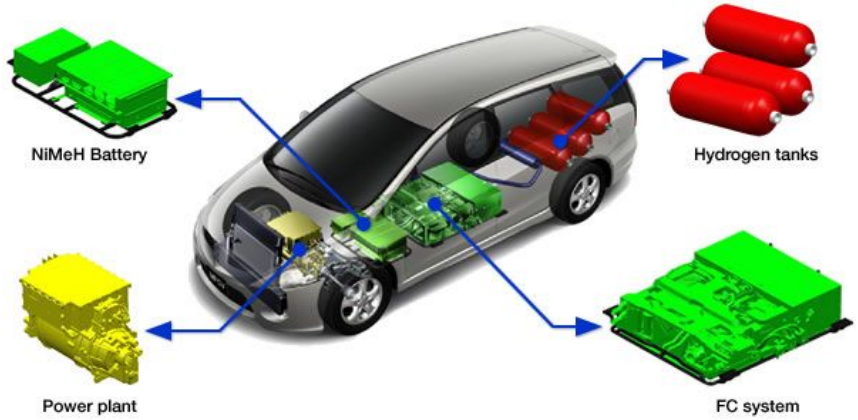
So you won't be surprised to hear that Shell favours Blueprints over Scramble. Both, however, describe a world in which a *portfolio* of solutions is needed to combat climate change – no single solution being capable of reducing $CO_2$ emissions on the massive scale required.

In power generation, this includes renewable energies, energy efficiency, Carbon Capture and Storage (CCS) – and others. In mobility, it includes GTL, biofuels, all manner of electric vehicles…and, of course, Hydrogen ICEs and Fuel Cell Vehicles.

Nor are these solutions mutually exclusive. On the contrary, they are often inextricably linked – for example, the production of Hydrogen from biomass or CCS; while CCS can be combined with energy efficiency programmes to even greater effect. That's why Shell is active in developing such a broad range of energy sources and technology solutions.

### *Hydrogen: the only pure $CO_2$-free drive-train*

But within this portfolio of solutions, one thing is clear: Hydrogen will play a key role – for power generation; as a fuel; and for fuel cell application. Indeed, while auto drive-train technology is undoubtedly improving – as is energy efficiency and electrics – the fact remains that the FCV is the *only pure $CO_2$-free drive-train*.




Not only do FCVs emit just water vapour and heat – significantly improving air quality – they are also very energy efficient, using 40%-60% of hydrogen's energy, compared to the 30% used by conventional vehicles. They are also much quieter, reducing noise pollution considerably. And while cost remains a key issue, it is recognised that fuel cells have the potential to be produced for even *less* than traditional combustion engines, as there are fewer internal moving parts.

So while there are still some technological hurdles to overcome, none are considered insurmountable. Indeed, investment is rocketing. For example, last year General Motors announced that over 500 fuel cell experts from advanced development laboratories would be moving to core engineering functions in order to prepare for future production; while Daimler has announced that it could produce FCVs that are competitively priced with conventional vehicles as early as 2012.

Venture capital also gives a good indication. For example, Shell has helped create two major VC funds in North America and Europe: Conduit, which invests in fuel cell solution developers such as PEMEAS; and Chrysalix, which invests in hydrogen generation and purification technology. When

Conduit sold its investment in PEMEAS to BASF, it made a three-fold profit in just three years. So the momentum is building fast.

Governments are equally as enthusiastic: for example, the European Union has increased its funding of Hydrogen and fuels cells to EUR 4-500 million between 2007-2013; while the Japanese government recently announced a five year, $1.3 billion FCV development programme. For its own programme, the US Department of Energy has requested $196 million – a four-fold increase over 2006. And the list goes on…

Based on the current development plans of OEMs, it is therefore generally recognised that the mass commercialisation of FCVs will begin around 2020. To this end, Shell has restructured its organisation to prepare for Hydrogen's transition into the mainstream, bringing it into our Downstream Fuels portfolio, alongside gasoline, diesel, LPG, CNG – as well as biofuels and GTL.


Our aim is now two-fold: to move to green – or "fully renewable" – Hydrogen as fast as possible; and help accelerate the mass roll-out of FCVs. Our credo? To "learn by doing", which is exactly what we've done over the last nine years, building Hydrogen stations on three continents. And a great deal has been learnt.

### *Urban mini-networks: the bridge to commercialisation*

But if Industry is to achieve its 2020 goal, it now needs to ramp up activity; move from low-use, stand-alone demonstrations, to building the foundation for longer-term mini-networks. Comprising clusters of consumer-friendly retail sites, such networks will play a crucial role in bridging the gap between current demonstration projects and a full infrastructure roll-out.

But this cannot be achieved by one company alone. It must be a coordinated effort, comprising hundreds of vehicles from different car companies; at least four combined hydrogen and gasoline refuelling stations; two or more energy companies; and two fleet owners, with hydrogen sourced from central production. Only in this way can we co-ordinate the mechanisms that build long-term investment and supply chain confidence, supported by a regulatory framework and public support. As importantly, it will allow us to better understand the experiences and needs of consumers in using hydrogen-fuelled vehicles.

So how do we get these mini-networks off the ground?

Well, location is obviously crucial – high density population areas, where 100,000 FCVs represent a mere fraction of the number of potential users. These usually also coincide with the production of industrial Hydrogen. Clearly, fleet companies will play a key role here. Cities like Tokyo, New York, Shanghai and LA, where Shell is already working closely with OEMs from the US, Europe and Asia to build retail facilities where we see FCVs being introduced.

And this highlights another key factor – the alignment of priorities and timescales; OEMs talking to energy companies to share information on numbers, dates and locations where FCVs will be introduced in order to trigger investment in infrastructure and ensure maximum impact.

***"Based on the current development plans of OEMs, it is therefore generally recognized that the mass commercialization of FCVs will begin around 2020."***


**WHITE PLAINS**: NY Mayor Joseph Delfino (left), Shell Hydrogen's Phillip Baxley and City of White Plains commissioner of public works Bud Nicoletti open White Plains

Hence Shell's recently dedicated Hydrogen fueling facility at White Plains in New York, which opened last November. Part of a US Department of Energy programme, it is already delivering 700 bar Hydrogen to GM Equinox FCVs being introduced into the New York City metro area.

**TONGJI, SHANGHAI**: Shell opened Shanghai's first hydrogen fueling station in November 2007 with Tongji University and the China Ministry of Science and Technology

In the same month, we also helped launch the very first Hydrogen refueling facility at Anting, in Shanghai's International Automotive City. Operated by Tongji University, under the auspices of the Chinese Ministry of Science & Technology, it serves a fleet of FCVs and buses in the region. As well as providing financial support, Shell has also sponsored the station's learning centre, and given safety advice and training.

In short, we are testing real-life vehicles in real-life conditions and building the foundation for future mini-networks.

But there is nothing like legislation to concentrate the mind of Industry and encourage local investment. You only have to look at California to see the impact of their Zero Emission Vehicle – or ZEV – mandate. This requires the six largest automotive companies to deploy, collectively, 7,500 electric and hydrogen cars, and 60,000 plug-in hybrids between 2012 – 2014.

And the fruits are already clear to see: 24 hydrogen stations currently operate in the San Francisco-Sacramento corridor and Great Los Angeles and San Diageo regions, serving FCVs and transit buses, with a further 10 stations already in the planning stages. That's more FCVs and hydrogen refuelling stations than anywhere else in the world and last year they clocked up one million zero emission miles.

Nor is California afraid to change its vision as it gains in knowledge and experience.

Only recently, the California Air Resources Board – or CARB – voted to adjust the number of battery-powered and Hydrogen FCVs sold by 2014 in order to allow more time to develop this technology for commercialisation. This will also encourage the deployment of more plug-in hybrids to help meet ZEV requirements in the medium term – a major step towards putting more cleaner cars on the road.

In fact, key issues are already being thrashed out as a result of direct experience. For example, there's been debate as to whether fuel cell buses should be replaced by hybrids on the grounds that they are too expensive to operate and maintain. But CARB is sticking to its guns and poised to add a further 12 buses to its fleet, pointing out that the next generation will actually be more reliable and cheaper to run than diesel.

Shell, of course, is right in the thick of it and proud to be an active member of the California Fuel Cell Partnership Steering Team.

In the summer, we will also be opening LA's first combined Hydrogen and gasoline station on Santa Monica Boulevard in West Los Angeles, manufacturing Hydrogen on site via an electrolyser. Supporting a US Department of Energy programme, it will serve FCVs being introduced by GM and others into the area and give consumers a real taste for the

***"It will obviously be some time before we can manufacture green Hydrogen at scale, but we're working on it…"***

future; one where it's just as convenient to refuel their FCV as it is a conventional motor.


**West Los Angeles**: Shell's newest hydrogen station opens in Los Angeles later this year.Hydrogen will be produced on-site,via an electrolyzer

And so to our second goal…

### *Shell: investing significantly in clean/green Hydrogen*

Currently 95% of Hydrogen is manufactured using natural gas. While this produces fewer $CO_2$ emissions than gasoline production, they are still significant and moving to more renewable sources remains a key objective for Shell.

It will obviously be some time before we can manufacture green Hydrogen at scale, but we're working on it…forging partnerships with ground-breaking businesses such as Virent Energy Systems. Almost a year ago, we began a five-year joint development agreement to further commercialise its BioForming™ technology, which enables Hydrogen to be produced economically from renewable glycerol and sugar-based feedstocks.

We're also committed to advancing the next generation of biofuels, which won't compete with food crops. We've already started building a pilot facility in Hawaii to grow marine algae and produce vegetable oil which can be converted into biofuel.

In the meantime, it's vital Industry pushes ahead with solutions for clean Hydrogen – especially Carbon Capture and Storage or CCS. Indeed, the Intergovernmental Panel on Change Climate has identified CCS as the most promising technology for the rapid reduction of global emissions – by up to 55% by 2100.

Shell is therefore spearheading efforts to facilitate its development and wide-scale deployment - on both a political and technical level. Again, it is a concerted effort, working with research institutions, national geological services, other energy companies and policy advocacy efforts worldwide.

We're also developing our own large-scale CCS demonstration projects in Australia and the Netherlands. As with Hydrogen, we believe it essential to 'learn by doing' in order to reduce costs, accelerate technology development and ultimately make CCS commercially viable on the back of emissions trading schemes alone.

For example, we're providing substantial technical services to ZeroGEN for the construction of the world's first full-scale demonstration of clean coal technologies in Queensland, Australia. In this ground-breaking project, ZeroGEN's Integrated Gasification Combined Cycle power generation plant will convert coal into synthesis gas, removing $CO_2$ to produce hydrogen-rich fuel which will be used by a high-efficiency turbine to generate electricity. Up to 70% of the plant's $CO_2$ emissions will then be stored underground in deep saline aquifers.

Clearly, Industry is prepared to make significant investments to get demonstration projects off the ground – but they won't happen without economic incentives to bridge the cost gap. These are now required as a matter of urgency.

But while CCS remains a key solution for the production of large-scale, clean Hydrogen, there are also other things we can do to reduce $CO_2$ emissions in the manufacturing process. Just two examples: since last Spring, Shell has been operating a forecourt reformer from H2Gen at our Westhollow R&D facility, where feedstock options such as Natural Gas and bio-feedstock are being evaluated. We've also undertaken a techno-economic evaluation of converting syngas from coal or biomass into clean/green Hydrogen in local settings, such as India or California.

***"Clearly, Industry is prepared to make significant investments to get demonstration projects off the ground."***

### *The electric mobility revolution has begun*

So, clean, green Hydrogen is on its way. What, then, of the more immediate future? With our clear focus on FCVs, you may think Shell has no appetite for any other, near-term options. Far from it. The lessons of California show that there are no hard and fast rules here, nor a single winner. We must be ready to adapt in the light of technology development and experience. After all, we are all on the same side here and a revolution does not happen overnight.


But a revolution in electric mobility does indeed seem certain. After all, hybrids already exist; battery electric vehicles are out there; and plug-in hybrids can be made today. Battery costs have also come down, and the range and cost will continue to improve. The only uncertainties are timing and the end game.

At Shell, our view is therefore that there is room for everything – electric, hybrid electric, plug-in hybrid and Hydrogen ICE – at least in the near-term until we're ready for the mass roll-out of FCVs. As the only pure $CO_2$-free drive-train, however, this must remain our ultimate goal.

### *Conclusion*

To sum up, then, the Hydrogen industry now stands at a pivotal juncture: investment is rising, costs are falling and technology continues apace. Hundreds of FCVs have been demonstrated successfully and yet more Hydrogen refuelling stations are being put in place. In short, Hydrogen is no longer simply a glorious vision – it is happening now, in cities around the world – including here in the United States. There is broad consensus that the mass roll-out of FCVs by 2020 is absolutely achievable.

But as Shell's global energy scenarios clearly demonstrate, no outcome can be guaranteed and the dice could go either way. It is therefore essential that we now to step up our game – from single, low-use demonstration projects to building the foundation for urban mini-networks.

It means choosing the right locations, the right partners, supported by the right policies and incentives. We only have to look at the example of California to see the how all the elements can fall successfully into place.


Above all, it means having the right dialogue – regular, open, transparent – not just with OEMs, but with all the other stakeholders in the value chain. Only by aligning our goals and sharing our experiences can we maximise impact and accelerate technology development. Because while research remains the lifeblood of our business, it is all for one purpose and one purpose only – to transform ideas into commercial reality; and *that* must remain our goal.

Thank you

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***"One thing, however, is certain: by 2100, the world's energy system will be radically different from today's. Renewables will make up a large part of it and humans will have found ways to deal with air pollution and GHG emissions. Energy efficiency will also have improved significantly."***

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