18th World Hydrogen Energy Conference 2010 – WHEC 2010 Proceedings

Speeches and Plenary Talks

Editors: Detlef Stolten, Bernd Emonts

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Speeches and Plenary Talks

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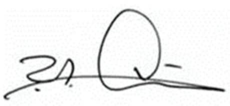
Foreword

T. Nejat Veziroğlu, President, International Association for Hydrogen Energy, USA

These are challenging and exciting times. Ours is a world of diminishing natural resources, global environmental problems, and an interdependent international economy heavily fueled by traditional forms of energy. Concern on global environmental problems caused by fossil fuels is growing. This year we have been witnessing most damaging floods in the United States, Europe, Pakistan and China. Earlier, we have witnessed most deadly forest fires in California, Spain, Greece and Russia. These are all produced by the global warming and climate change resulting from the use of fossil fuels. Our challenges are then to develop new, clean renewable energy sources, to safeguard the quality of the environment, and to ensure the continued progress of our civilization. Our best hope for energy security and sustainable future is the development of sensible energy options, with one of the most promising options being the Hydrogen Energy System.

Biennial World Hydrogen Energy Conferences (WHECs) are the flagship conferences of the International Association for Hydrogen Energy (IAHE). They provide a platform for the world's distinguished energy and environmental scientists and engineers for presentations and discussions of the latest research results in the field of Hydrogen Economy. In keeping with the growing importance of the Hydrogen Energy System, the 18th WHEC 2010 Conference was one of the biggest and the best of the World Hydrogen Energy Conferences. The proceedings of the conference – consisting of more than 450 presentations and articles – have been put together in six volumes. No doubt, they will serve as useful reference and resource material for many years to come.

I strongly recommend this excellent six volume proceedings to energy engineers, industrialists, environmentalists and decision makers, as well as to those interested in the future of humankind and the welfare of the planet Earth.



Preface

A comprehensive and renowned conference offers the opportunity to extend the scope beyond mere technical issues. It allows for having strategic presentations and discussing aspects of market introduction, industrial and Governmental target setting as well as approaches to and actions for implementation. The 18th World Hydrogen Conference 2010, WHEC2010, succeeded in exploiting this opportunity and satisfied the expectations. Strong political support in Germany and in the State of North Rhine Westphalia in particular made it possible to have high profile decision makers at the conference presenting their strategies first hand.

Hence, a full day was dedicated to plenary speeches and overview talks. The WHEC2010 came handy at a time when fuel cells are developed to suit the requirements for vehicles, except for cost and durability. At a time when the competition with batteries and whether or how a hydrogen infrastructure can be established and afforded were hot topics in the public debate, which needed answers on a well informed basis. Considering fuel cells and hydrogen at a time at one conference and supplementing it with the current knowledge on batteries and hybridization clarity on the future role of these technologies was gained. Very likely fuel cells and batteries will coexist in a future of electrified vehicular transport. Their different technical characteristics will open the doors to different market segments. Implementing hydrogen infrastructure, being a requirement for fuel cells in transport, is considered doable and affordable.

This book presents the speeches and overview papers from the plenary session of the WHEC2010 on May 17, 2010.

Six further books of this issue contain the papers of the oral and poster presentations, except for the introductory talks of the sessions. The latter are published separately by Wiley in a book named Hydrogen and Fuel Cells . In total the 18th WHEC is documented on over 3800 pages in a structured way in order to reach the broad spectrum of potential readers.

The editors gratefully acknowledge the strong and sustained support of the State of North Rhine Westphalia and the EnergieAgentur.NRW.

March 2011

Detlef Stolten

Chairman of the WHEC 2010

Bernd Emonts

Coordinator of the WHEC 2010 Student's Day

Greetings, German Federal Government

Minister Dr. Peter Ramsauer, Federal Ministry of Transport, Building and Urban Affairs, Germany

Begrüßung

Sehr geehrter Herr Kollege **Prof. Wan Gang**, (Minister für Wissenschaft und Technologie der Volksrepublik China) sehr geehrter Herr Ministerpräsident **Dr. Rüttgers**, (Ministerpräsident NRW) meine sehr geehrten Damen und Herren!

1 Einleitung

In dieser Woche ist Essen nicht nur Europas Kulturhauptstadt, sondern auch die „Weltwasserstoffhauptstadt“! In dieser Woche treffen sich hier in Essen Wasserstoff-Experten aus der ganzen Welt. Und ich freue mich besonders, sehr geehrter Herr Kollege Prof. Wan Gang, dass Sie meiner Einladung gefolgt sind. Diese wichtige Konferenz gewinnt durch Ihre Anwesenheit noch einmal deutlich an Gewicht. Ich freue mich auf Ihren Beitrag und sehe ihm mit Spannung entgegen.

Auf dieser Konferenz wird nicht zuletzt über die Zukunft der Mobilität diskutiert. Das ist gut so. Denn Mobilität ist ein unverzichtbarer Teil unseres Lebens. Die Teilhabe des Einzelnen am gesellschaftlichen und kulturellen Leben, der Weg zur Arbeit und der Transport unserer Güter: All das ist ohne moderne Mobilität nicht denkbar.

Gleichzeitig wissen wir: Gerade angesichts des Klimawandels muss der Verkehr umweltfreundlicher werden und dabei bezahlbar bleiben. Wir setzen nicht auf Restriktionen. Das würde bedeuten, Mobilität zu begrenzen und Menschen von Mobilität auszuschließen. Genau das wollen wir nicht!

2 Innovationen und Neue Technologien

Wir setzen stattdessen auf Innovationen und neue Technologien. Dazu gehört die Wasserstoff- und Brennstoffzellentechnologie. In diesen Zukunftstechnologien liegt eine große Chance. Diese Chance müssen wir nutzen. Für den Klimaschutz. Für unsere Unternehmen. Für zukunftsfeste Arbeitsplätze. Es geht um unsere globale Wettbewerbsfähigkeit. Deutschland muss international ganz vorne mit dabei sein bei neuen Effizienz- und Nachhaltigkeitstechnologien.

Neben der Batterie spielen Wasserstoff und Brennstoffzelle eine zentrale Rolle für die Mobilität und Energieversorgung von morgen. Wir fördern die Elektromobilität in ihrer ganzen Bandbreite. Das ist im Übrigen nicht nur auf den Straßenverkehr begrenzt. Brennstoffzellen können z. B. auch für die Bordenergieversorgung von Flugzeugen oder für die Stromversorgung von Schiffen eingesetzt werden.

Wir haben in Deutschland zwei umfangreiche und wegweisende Programme verabschiedet: Das Nationale Innovationsprogramm Wasserstoff- und Brennstoffzellentechnologie – kurz:

NIP - und das Programm Modellregionen Elektromobilität. Mit dem NIP sollen Produkte und Anwendungen aus der Wasserstoff- und Brennstoffzellentechnologie über Demonstrationsprojekte bis zur Marktfähigkeit befördert werden. Dafür stellen Bundesregierung und Industrie bis 2016 1,4 Milliarden Euro zur Verfügung.

Der Energieträger Wasserstoff spielt in diesem Gesamtzusammenhang eine ganz wichtige Rolle: Er ermöglicht die Nutzung von erneuerbaren Energien im Verkehrssektor. So schaffen wir mittel- bis langfristig eine Alternative zum Erdöl.

3 Bedeutung von Wasserstoff für eine Nachhaltige Mobilität

Noch bis zur ersten Ölkrise zu Beginn der 1970er-Jahre glaubte man, über nahezu unendliche Energiereserven zu verfügen. Heute wissen wir, dass das ein Trugschluss war. Inzwischen ist allen klar: Wir stehen vor gewaltigen Herausforderungen und einschneidenden Veränderungen.

Wir brauchen keine neuen Wunschträume. Wir brauchen realistische Ziele und den Mut, sie entschlossen zu verfolgen. Wir schaffen das. Ich bin zuversichtlich, dass wir Zeitzeugen einer Wachablösung und einer technologische Zeitenwende im Verkehrsbereich werden. Gewiss: Die Erfolgsgeschichte des Verbrennungsmotors ist noch nicht zu Ende geschrieben. Hier gibt es noch viel Entwicklungspotenzial. Aber nach der langen Dominanz des Erdöls schlagen wir mit der Elektromobilität und mit Batterie und Brennstoffzelle ein neues Kapitel auf. Und auch das wird eine Erfolgsgeschichte. Dafür können und müssen wir sorgen.

Die Wasserstoff- und Brennstoffzellentechnologie ist sauber und effizient. Wir können auf Wasserstoff als Energiespeicher für die Erneuerbaren Energien nicht verzichten. Und wir brauchen die Brennstoffzelle im Auto: Als Alternative und als Ergänzung zu den leistungs- und reichweitenbeschränkten Batteriefahrzeugen, für die langen Strecken, für große Autos, für Busse, aber auch auf dem Wasser und in der Luft.

Die Wasserstoff- und Brennstoffzellentechnologie besitzt das Potential, schon bald eine entscheidende Rolle in unserer Energieversorgung zu spielen: Sowohl für die Strom- und Wärmeerzeugung in unseren Häusern, als auch im Hinblick auf unsere künftige Mobilität. Unser Nationales Innovationsprogramm und seine Projekte zeigen: Wasserstoff und Brennstoffzellen sind längst über das Stadium der reinen Forschung hinaus. Schon heute sind anwendungsreife Produkte im Einsatz: Autos und Busse, Schiffe, Heizgeräte und vieles mehr. Die Bilanz ist in fast allen Bereichen zufriedenstellend.

Zwei Projekte liegen mir als Bundesverkehrsminister besonders am Herzen: Die **Clean Energy Partnership** und die **H2 Mobility.**

4 Clean Energy Partnership

Seit einigen Jahren besteht in Berlin und Hamburg die Clean Energy Partnership, kurz CEP. Hier sind führende Unternehmen eine echte Partnerschaft eingegangen: Automobilunternehmen wie BMW, Daimler, Ford, GM/Opel und VW – im März ist Toyota hinzugekommen; wichtige Mineralölfirmen wie Shell, Total und Statoil; Unternehmen aus der Energie- und Gasbranche wie Vattenfall und Linde; bedeutende Verkehrsunternehmen wie die Hamburger Hochbahn und die Berliner BVG.

Das ist eine starkes Bündnis für Klimaschutz und Mobilität. Mit dieser strategischen Partnerschaft soll Wasserstoff als „Kraftstoff der Zukunft“ etabliert werden. Seit 2008 wird diese Initiative vom Bundesverkehrsministerium gefördert. Alle beteiligten Unternehmen stellen ihren unternehmerischen Mut unter Beweis. Sie haben begriffen: Wir sind bei den Antriebstechnologien an einem Wendepunkt angelangt. Wer hier rechtzeitig die richtigen Lösungen und Technologien entwickelt, wird auch in Zukunft Käufer und Märkte finden.

5 H2 Mobility

Im vergangenen Jahr haben sich darüber hinaus bedeutende Unternehmen der Automobilindustrie und der Energiewirtschaft wie Daimler, EnBW, Linde, NOW, OMV, Shell, Total, und Vattenfall unter dem klangvollen Namen „H2 Mobility“ zusammengeschlossen, um den flächendeckenden Aufbau der Wasserstoffinfrastruktur in Deutschland vorzubereiten. Dies ist enorm wichtig, denn ab 2015 sollen die ersten serienmäßigen Brennstoffzellenfahrzeuge auf deutschen Straßen unterwegs sein. Das klappt natürlich nur mit einem entsprechenden Tankstellennetz.

Mit dem Projekt „H2 Mobility“ wird dieser Aufbau zusätzlich auf eine solide wissenschaftliche und für die Unternehmen wichtige betriebswirtschaftliche Basis gestellt. Auch hier ziehen alle relevanten Partner an einem Strang. Eine Situation, die ich mir im Übrigen bei der Frage des Aufbaus der Aufladestationen für die batteriegetriebenen Fahrzeuge auch wünschen würde.

6 Schluss

Sie sehen, im Wasserstoff- und Brennstoffzellenland Deutschland tut sich Einiges. Das hat viel mit partnerschaftlichem Denken zu tun und damit, dass in diesem Bereich alle Beteiligten den Mehrwert offener Kooperationen erkennen.

Wir müssen diese nachhaltigen Technologien im Verkehrs- und Energiebereich marktreif machen. Wir müssen ausloten, wie wir – in enger Zusammenarbeit mit den Industriepartnern - die richtigen politischen Rahmenbedingungen zur Markteinführung schaffen können. Wir müssen aus der Lernphase heraus und in eine Phase kommen, die standardisierte, technisch stabile und kundentaugliche Lösungen ermöglicht. Wir wollen die internationale Zusammenarbeit vertiefen und verstärken.

Das entscheidende Scharnier und zugleich der Taktgeber in diesem Gestaltungsprozess sind Sie, die Vertreterinnen und Vertreter der Wasserstoff- und Brennstoffzellenbranche. Ihre Arbeit ist die Basis für den Erfolg unseres Innovationsprogramms. Der Weg zum Wasserstoff und zur Brennstoffzelle braucht einen langen Atem und ein klar umrissenes Ziel. Wir wollen mit dieser Zukunftstechnologie noch in diesem Jahrzehnt auf dem Markt sein!

Diese Konferenz ist deshalb ein wichtiger Baustein, um unsere Vorstellungen von einer zukunftsfähigen Infrastruktur, einem nachhaltigen Verkehrssystem ohne Abhängigkeit von fossilen Brennstoffen Wirklichkeit werden zu lassen.

Ich wünsche der Weltwasserstoffkonferenz einen erfolgreichen Verlauf und allen Teilnehmern gute Gespräche und anregende Diskussionen. Vielen Dank für Ihre Aufmerksamkeit!

Greetings, NRW Government

Dr. Jürgen Rüttgers, then Minister President of the State of North Rhine-Westphalia, Germany

Not long ago I was in Abu Dhabi where I had the opportunity of looking at the plans drawn up by Sir Norman Foster for the environmentally friendly Masdar City. A fascinating vision. The city will manage without cars. There will be no greenhouse gas emissions. There will be no need for refuse dumps. The city will produce its own electricity. And it will do without fossil fuels. This is the vision of an ideal city of the 21st century.

Whether it is feasible remains to be seen. What is important is that we actually have this vision. This vision means we are entering a new era. In the industrial era that is now coming to an end, industry and environmental protection were diametrically opposed. In the new industrial era that is now beginning, they will be two sides of the same coin. The great innovations of the 21st century are to be found in connecting the two. This is the next big innovation cycle for growth, prosperity and jobs.

Here in North Rhine-Westphalia, we intend to be pioneers blazing a trail into the new era

Here in North Rhine-Westphalia, we intend to be pioneers blazing a trail into this new era. We are an industrial region. And we intend to remain an industrial region. But we want to become the most eco-conscious industrial region in Europe. This is not only decisive for the battle against climate change. It is above all where the great innovations of the 21st century are to be found, which will create innovations and jobs.

Specifically, this firstly means that production must become more climate-friendly and efficient. This is true of all branches of industry, but particularly of energy. This means that old coal-fired power plants will have to be shut down as fast as possible. And no new ones will be approved unless they significantly reduce their CO_2 emissions and improve their energy efficiency.

We must use our resources more efficiently. Raw materials are by far the greatest cost factor in manufacturing industry today, accounting for about 40% of costs. Scientists say that we could save 20% of raw materials consumed by improving efficiency – by recycling and by developing new materials. However, this also means that access to raw materials must be safeguarded. I have therefore long been in favour of an integrated concept for raw materials.

This means that, together with the EU, Germany must ensure that conditions for fair competition are enforced in the G8 and G20 groups and that raw material monopolies are effectively counteracted. The Federal Government must promote its own concepts as well as research and development for new metals and the recycling of rare materials. And industry must play its part by establishing strategic alliances and new technologies for the effective recycling of raw materials in the future.

We are developing a second, decentralized energy path

Secondly: We must expand the use of renewable energy sources by means of a second decentralized energy path. Decentralization is the key to the energy of the future. This involves renewable energy sources in our own backyard, where we live and work. This is why we are encouraging solar and wind energy, combined generation of heat and power, geothermal heat and bioenergy – in order to save CO_2, so that we are not dependent on oil and gas and the whims of the energy multinationals.

Here is just one example. By 2020, here in North Rhine-Westphalia we intend to double the amount of energy produced from biomass to almost 18 billion kilowatt hours. We will then be able to cover 20% of the electricity requirements and 10% of the heat requirements of our private households.

We must invest in modern environmental technologies

And also a third point: We must invest in modern technologies that create growth and at the same time conserve resources – for example in fuel cell and hydrogen technology. This offers great economic opportunities. Alone with the hydrogen produced by our industry we would be able to operate about 260 000 cars and almost 6 000 buses. And we wouldn't have to produce even one additional molecule of hydrogen. We want to exploit this opportunity.

For our lighthouse project "NRW Hydrogen HyWay", we in North Rhine-Westphalia are providing €200 million together with the Federal Government, the EU and industry: for our infrastructure, our fleets of vehicles and for stationary plants.

We also intend to produce hydrogen from renewable sources in future. Special projects are already in progress: with sewage gas in Bottrop, with algae in Bochum and Bielefeld, and solar energy in Jülich. And we also have the necessary infrastructure. A 240-kilometre hydrogen pipeline already runs from Leverkusen to the east of the Ruhr region. I am very interested in hearing what paths the conference will propose today for the future.

However, it is not only the opportunities for hydrogen that are fascinating but also those offered by CO_2. It is, after all, not only important to save CO_2 but also to obtain new products from CO_2 in order, for example, to convert carbon dioxide into biomass using microorganisms or directly into useful materials. We are expecting great innovations here. There is no sense in simply storing CO_2 underground. This is why, together with industry, we want to establish a national CO_2 research institute.

Even today, North Rhine-Westphalia is already one of the most important locations in the world for modern environmental engineering with more than 250 000 people employed in the environmental industry and a turnover of about €45 billion. We want this to grow even further.

Example of electromobility

Let me just give one last example of innovative environmental technology that I find particularly fascinating. I am speaking of electromobility. We want to make North Rhine-Westphalia the first large-scale model region for electric cars in Europe. By 2020, we want to have 250 000 electric cars on the road. We are making €60 million available to promote research and development. We are constructing electric cars and a network of charging stations. And we are developing new high-performance batteries so that these cars can be driven all round the country.

And this shows just how important impulses from politics are for the development of such technologies. It was quite right that in the USA President Obama insisted that pollutant emissions from new vehicles have to be reduced by 30% by the year 2016. It was also quite right that the EU decided that from 2021 no new building may consume more energy than it produces. These are as yet the most stringent standards in the world. But such standards are indispensable.

The Innovation City project is unique in Europe

If we combine all these innovations then we can also break new ground in urban development. Together with the "Initiativkreis Ruhr", an association of 61 German and international companies, I recently gave the go-ahead for an *Innovation City* in the Ruhr region: for a neighbourhood with about 50 000 inhabitants, which will set a new trend for an environmentally conscious lifestyle and energy-efficient industry. Not on a green field but right in the centre of town. Together with local citizens. Urban renewal combining high tech with the needs of the citizens makes this project unique in Europe.

The future belongs to environmentally aware industrial regions – such as North Rhine-Westphalia. We will be successful if everyone plays their part. Gandhi once said "You must be the change you want to see in the world." This should be our motto – not only for us here today in Essen but also throughout the world. I wish you every success with your conference.

Hydrogen Fuels Mobility

Lutz Lienenkämper, then Minister for Construction and Transport of NRW, Germany

1 Welcome / Introduction

Special welcome to:
Professor (Dr. Ing) Detlef Stolten, Conference chair
Professor T. Nejat Viziroglu, IHAE chair

After almost four days, WHEC World Hydrogen Energy Conference 2010 is drawing to a close. It has been an interesting programme, giving us a comprehensive and up-to-date overview of the latest facts and figures, as well as an outlook for the future.

The message is clear: hydrogen and fuel-cell technology has been making great strides – mind you, this is not always obvious to the layman – and many applications are on the verge of market entry. In some areas, such as the secure energy supply to computer and communications facilities, the breakthrough to the markets has already been achieved.

Given the many structured approaches to turn this promising technology into worldwide commercial success and the commitment shown by the expert community, there is really no doubting the fact that fuel-cell technology, along with hydrogen as the source of energy, is going to make an entry into the transport sector – and very soon, too. I will say more about this later on.

As Transport Minister, I am only too happy to pay attention to these signals, given that they are hinting at promising solutions especially in the area of regional mass transit. Let me assure you that the NRW State Government is prepared and willing to provide substantial backing here.

2 Federal / Nationwide Activities

In the decade ahead, mobility as we know it is set to change, in technical and technological terms, in economic terms and in terms of how it is organised. In order to safeguard our mobility in the long run, we need to develop new and sustainable fuel, propulsion and vehicle concepts.

Electrification of vehicles is what everybody talks about these days. Just recently, on 3 May, the "National Electromobility Platform" held its inaugural meeting, chaired by German Chancellor Angela Merkel and attended by numerous players from the industry and research sectors. The Federal Government is taking an unambiguous stance and will be driving forward the gradual transition from combustion engines to alternative systems such as fuel cells, batteries or hybrids.

However, it is important to not focus on just one technology; in line with the Federal fuels strategy, the vast potential for greater efficiency of traditional petrol engines will be taken into consideration, especially in conjunction with the use of modern fuels.

At the end of the day, it is all about efficiency and sustainability. At the same time, electromobility is a vehicle for the introduction, into the transport sector, of renewable energy sources in the shape of electrical and/or hydrogen power.

During recent years, the Federal Government has launched a range of powerful programs to support and promote the development of new transport technologies. Under the National Hydrogen and Fuel-Cell Technology Innovation Programme (NIP), 700 million Euros are going to be made available by the Federal Government. A lot of that is earmarked to promote fuel-cell driven vehicles. Under the Second Economic Stimulous Package, the same amount of money is going to electromobility battery research. This puts Germany in a very favourable position to compete with other industrialised nations.

The industry, too, has shuffled for position. In September, 2009, some major vehicle OEMs, oil corporations and energy suppliers signed a Memorandum of Understanding, entitled “H2 Mobility”, aiming at the development if a hydrogen infrastructure in Germany. But 2020, up to 1000 hydrogen filling stations are going to be built in Germany. Similar initiatives are being launched across Europe.

More or less at the same time, a Letter of Understanding was signed by nine vehicle OEMs aiming at bringing fuel-cell powered cars to the market. The idea is to drive forward fuel-cell development in order to get hundreds of thousands of such vehicles on the road by 2015. Those are inspiring and positive signals that demonstrate commitment and dedication as well as the state of development this technology has achieved.

3 Activities and Plans in North Rhine-Westphalia

It goes without saying that lasting, safe and affordable supply of energy is of great significance to North-Rhine-Westphalia, a centre of industry and energy. Efficiency is the buzzword when it comes to converting and consuming energy.

It is also at the focus of our energy and climate strategy: with our ambitious goals – reduction of CO_2 emissions by 81 million tonnes between 2005 and 2020, or 44 per cent of the nationwide objective – we have taken on the role of catalyst in Germany and Europe. Naturally, my work centres on the transport sector.

The sector accounts for roughly 20 per cent of the carbon dioxide emitted in Germany. Twelve per cent comes from the motor car. This means that any forward-looking energy and climate policies must definitely address the issue of mobility. Mobility is one of the cornerstones of the modern industrialised society. Demands on mobility are rising all the time.

In the area of mobility, North Rhine-Westphalia has for quite a while been maintaining intense and good cooperation with the Federal Government, especially the Ministry of Transport. And we are keen to continue to play a major role in improving and implementing the necessary National Development Programmes.

This is against the backdrop that the North Rhine-Westphalia government under its holistic approach to energy and fuels, is carrying out a range of mobility programmes identical to the Federal schemes. More specifically, these are the three key principles of our strategy:

1. Energy security

Protecting the supply of energy by becoming less dependent on oil (more diverse energy mix, putting fuel supply on a broader basis, use of domestic energy sources, use of “domestic” secondary sources such as electricity, man-made fuels or hydrogen)

2. Sustainability

Protecting climate and environment by increasing the use of renewable energy in the transport sector and by making propulsion technologies as efficient as possible.

3. Economic viability

Though cuts in fuel consumption, low-cost fuels, sustainable fuel supply and by keeping the cost of purchase down.

With an eye on achieving energy efficiency, the NRW Government, mirroring efforts by the Federal Government and the EU, has come up with a twin-track “holistic” fuels and propulsion strategy:

A) clean fuels combined with efficient propulsion systems, based on optimised combustion engines (e.g. XTL fuels, second and third-generation bio fuels, CNG or biogas);

B) step-by-step electrification of drive train, incorporating the full spectrum of technical options (i.e. hybrid technology including plug-in and diesel-hybrid solutions), battery-powered cars as well as fuel-cell and hydrogen technology

According to the State Government, electromobility must be defined as “driving with an electric motor”. Our energy and climate policy pays special attention to electric mobility that is “visible”, in other words, not limited to private motor cars. Instead, we would like to see light commercial vehicles, city buses or local government fleets utilise their full potential of increasing energy efficiency and achieving climate protection.

Electric propulsion systems therefore provide an outstanding perspective for the realisation of climate change targets in the transport sector. How good this will eventually turn out to be depends both on future increases in the efficiency of electric vehicles and on the efficiency of fuel production techniques.

The policy cornerstones described above have led to the NRW Electromobility Master Plan, which is designed to:

- Describe the importance of electric mobility and the opportunity it provides;
- Identify the need for action;
- Draw up implementation strategies that contain concrete steps to achieve the above objectives.

The issue of electromobility has also huge implications for North Rhine-Westphalia as a centre of the car industry. The transition from conventional engines to electric drive trains is set to trigger enormous changes in the motor sector and especially amongst automotive suppliers. It is therefore our aim to prepare for these changes and use the resulting economic opportunity for North Rhine-Westphalia.

Several industries have the chance to benefit from the changes, amongst them the mechanical engineering sector, the electrical and chemical industries as well as the energy suppliers.

4 Fuel Cells and Hydrogen Technology for North Rhine-Westphalia

Let me specifically address a very important component of electromobility – hydrogen or, more precisely, hydrogen-fed fuel cells. The North Rhine-Westphalia Government considers hydrogen to be a major element of the changeover to renewable energy sources.

The fuel-cell and hydrogen technology has all the hallmarks of a key technology with great economic potential. It is therefore one of the focal areas of the State Government's promotion and development efforts in the energy sector. I have said earlier that the results of this conference are encouraging us to continue to work on this issue, to step up our efforts, even. On Monday, my cabinet colleague, Economic Affairs Minister Christa Thoben, said that we had made a start by joining the Clean Energy Partnership (CEP).

Within CEP, North Rhine-Westphalia is going to give intense support to the introduction of hydrogen as a fuel for regional public transport. To this end, the NRW Government has devised a medium-term commercialisation strategy for hydrogen and fuel cell technologies.

This is essentially about broadening the skills base of local vehicle manufacturers and utilising the state's favourable infrastructure. Let us first take a look at the infrastructure:

In North Rhine-Westphalia, Air Liquid operates a 230-kilometre hydrogen pipeline between the Ruhr and Leverkusen, just north to cologne. This pipeline, already serving as a basis for hydrogen and fuel cell projects, is bound to move even more to the focus of strategic considerations. It runs parallel to a number of major transport routes in North Rhine-Westphalia, and is an outstanding means for getting hydrogen to the consumer.

Add to this the availability of large quantities of industrial hydrogen which experts reckon to be a key source of hydrogen for the duration of the transitional period up until 2030. Quantity, quality availability and affordability of hydrogen from industrial – technical and chemical – were at the focus of a study conducted by the Wuppertal Institute in collaboration with the Jülich Research Centre on a variety of technical and chemical processes. In North Rhine-Westphalia, some 260.000 passenger cars or almost 6000 buses could be operated with industrial hydrogen, without needing to produce an extra molecule. This is an opportunity we are not going to miss.

The best infrastructure is worth nothing without vehicles to use it. We all know that a couple of hundred fuel-cell vehicles are in use worldwide so far, and all manufacturers are gradually expanding their test fleets. Earlier, I mentioned the Letter of Understanding concerning the market entry of fuel-cell vehicles, you know, where hundreds of thousands of fuel cell cars were going to be in service by 2015.

On a parallel track, we in North Rhine-Westphalia put the focus on regional public transport, most notably on buses. We are currently working with partners from the public transport sector on a scheme to drive forward the use of fuel-cell hybrid buses. We firmly believe that FC buses are an interesting option when it comes to helping the technology achieve breakthrough. There are several aspects to support this theory, such as the visibility of the vehicles, high public awareness, commercial viability and infrastructural advantages through fleet operations.

As yet, however, vehicles are not available in sufficient numbers and, what is more, there is no real competition. We are eager to change this and open up to the market, using local technologies. In fact, we began to do this at an early stage. As early as 2006, the Transport Ministry carried out initial field trials with so-called midibuses in the city of Düsseldorf. Those are still in operation, and the scheme was extended in 2009 to cover the Ruhr. Additional vehicles are today running in Gladbeck, Bottrop and Herten.

In the meantime, the manufacturers of the midibuses, Gladbeck based Hydrogenetics Corporation, have translated the lessons learnt into a new vehicle concept. This was rolled out last week and is now being operated here at the conference in what we call a “Ride and Drive Event”.

We have launched another project in a joint German-Dutch venture. The objective is a scientific and technical assessment of the routine use in mass transit of no fewer than four bendy buses powered by a novel triple-hybrid system. The buses are going to be used on public transport routes in Germany and the Netherlands where they will be shown to a wider public. The buses are full of innovation. The concept vehicle is parked up outside. It is well worth your while having a look.

As we want to continue on the road we have embarked on, we are working on follow-up schemes to increase the number of vehicles. At the same time, we are initiating more development programmes in collaboration with additional partners, in order to encourage manufacturers.

With a view to improving the uptake of electric mobility, the State Government supports the establishment of charging points along public roads. In the summer of 2009, my department authorised local councils to designate signposted special roadside loading zones for electric vehicles.

The same measures could also be applied to fuel-cell driven cars. Moreover, electric vehicles, be they battery or fuel-cell powered, definitely profit from the new low emission zones.

5 Concluding Remarks

In the debate on electric vehicles and hydrogen or fuel-cell motors, we are facing a number of new issues. Pilot trials, new infrastructure (e.g. “extension cords”, hydrogen fuelling stations, smart grids, virtual power plants, storage), smart metering and driver behaviour call for closer co-operation of regional stakeholders, with a view to safeguarding the chances for success of innovating products and services, and to crack the market.

This multidisciplinary co-operation is very much in line with North Rhine-Westphalia’s so called “cluster” policy which aims to make the state’s business sector more competitive.

Success of the cluster policy hinges on action programmes and projects across various clusters. We refer to is as cross innovation. Electric mobility is a good case in point. Tomorrow’s mobility challenges can only be dealt with if a multitude of partners join together

– one only needs to look at the current co-operation of car manufacturers and energy suppliers in the area of vehicle electrification.

The future belongs to a variety of technical solutions to particular mobility issues. Electromobility needs to be viewed with technological neutrality. Whilst battery-powered cars and fuel-cell vehicles each have their advantages and drawbacks, depending on application and use, they complement each other beautifully. Industry has therefore opted for both tracks. As there will be no “this or that” both technologies should be developed under the heading “electromobility”.

I am sure this meeting has contributed towards highlighting the current developments with regard to the new propulsion systems. The opportunity is certainly there to be thrilled by this innovative technology during the “Ride & Drive Events”.

I am confident that the 2012 follow up in Toronto will be another milestone, building on the success of this conference. Thank you very much!

Fueling the Future: Hydrogen in the Automotive Industry

Dr. Dieter Zetsche, Daimler AG, Germany

1 A Brief Word of Thanks for the IPHE Award

Thank you very much, Dr. Steinle.

I think I can speak on behalf of all the “H2 Mobility” partners when I say that we view this award not so much as a symbol of recognition for what we’ve already accomplished, but more as an incentive to tackle the challenges ahead. And there’s lots to do.

Receiving this honor at such an early stage of our work can also be a burden — Barack Obama’s Nobel Peace Prize immediately comes to mind here. Now, it’s not my intention to compare our activities with the job of the President of the United States. Nevertheless, attempting to bring peace to the world does have one thing in common with the endeavor to establish a hydrogen economy: Both of them require a great deal of patience. One thing I can promise you is that we have enough patience. So with that in mind, I would like to express my heartfelt thanks to the IPHE for this award!

2 Introduction

Ladies and gentlemen,

- Our world has changed remarkably since the last WHEC was held in June 2008.
- First, we saw many banks fail, one after the other.
- Then many banks were nationalized.
- And now, several countries are threatened with bankruptcy.

Here in Europe, for example, we have the problem that while Iceland is plagued by too much volcanic ash, Greece has too little cash. (Basically, all of us are affected in both cases.)

Although a lot has happened in the last 24 months, practically no other industry is experiencing the kind of transformation that is currently affecting the automotive sector. Sooner or later, we will overcome the impact of the recession on the automobile markets. However, one fundamental process of change will continue: the paradigm shift regarding drive system technology. It’s inevitable that oil will become scarcer and more expensive, emission standards more restrictive, and customers more environmentally conscious. Taken together, all of this means that vehicles will have to become more electric.

Public attention is currently more or less focused on battery-electric mobility. However, I am convinced that the chances of success for electric vehicles equipped with fuel cells have never looked as good as they do now. The fact is that fuel cell technology is now ready to hit the market. What we have to find out is whether the market is ready for fuel cells. And that’s exactly the question I’d like to address today.

Let's imagine that this exhibition center is a dealership showroom. I'm the salesman and all of you are potential customers interested in buying a car with a fuel cell drive. As customers, you wouldn't be very interested in the math describing the chemical reaction of oxygen and hydrogen. You also wouldn't really care much whether the platinum-free membrane actually works or is just a PR gag. As experts, you'll be looking into these issues and many others over the next few days here in Essen.

For now, I'd like to come up with answers to three very simple questions that you as customers would probably ask:

- First: What can a fuel cell vehicle do?
- Second: How much does a fuel cell vehicle cost?
- And third: Where do you refuel a fuel cell car?
  (Anyone I've already won over at this point is, of course, welcome to pre-order a fuel cell vehicle from me.)

So let's look at question number one: What can a fuel cell vehicle do?

3 What Can a Fuel Cell Vehicle Do?

There's no way to answer this question without comparing fuel cell technology with the current "top dog" of drive system technology: the combustion engine. We know that the only way to keep our industry in the black over the long term is with green cars. However, customers believe that a new car must always be a better car as well — and environmental compatibility is only one aspect here. Individual mobility also needs to remain safe, comfortable, and flexible. With regard to these and other aspects, the combustion engine has been the measure of all things for more than 120 years now. So that's what we've got to beat.

There's no "miracle cure" in sight here. That's why efficient combustion engines will remain the most important lever for the time being when it comes to reducing CO2 emissions. Over the long term, we at Daimler are looking at a mix of different drive system alternatives. Specifically, these alternatives are partial electrification with hybrid drives, battery-electric vehicles, and, of course, electric cars equipped with fuel cells. I'm convinced that this combination represents the best response to the varied mobility requirements of our customers.

However, if the objectives are zero-emission travel over long distances and short refueling times, there's only one alternative to gasoline or diesel — and that's hydrogen. The market is in fact demanding solutions for long-distance driving. For example, according to surveys, almost 75 percent of all Germans believe that electric vehicles already have a minimum range of 300 kilometers or will achieve such a range in the near future. I'm basically an optimistic kind of guy, but as things stand today, a range like that isn't possible with a battery-electric system. Even the nominal energy content of lithium-ion batteries is still below 120 watt-hours per kilogram for automotive applications. That corresponds to only a fraction of the energy density of liquid fuels. To be exact, it's only one percent. In practice, this translates into a range of less than 200 kilometers.

The situation is completely different with hydrogen. Thanks to 700-bar technology, the Mercedes-Benz B-Class F-Cell can now drive nonstop for well over 400 kilometers. I also believe we'll break the 600-kilometer mark — without having to sacrifice any cargo space volume. Fuel cell technology is also absolutely competitive when it comes to the refueling time. It takes just three minutes to fill a tank these days, so there's no reason to spend the night at a refueling station if you've got a fuel cell.

We've also made tremendous advances in the past few years in terms of the durability of fuel cell stacks. One way of increasing a fuel cell's service life is to combine the unit with a "buffering battery." That cushions peak loads, which means that cell membranes last longer. Our fuel cell systems for buses can now operate for six years, and the technology we use is practically maintenance-free. At the moment, we expect fuel cell stacks for passenger cars to last for more than 110,000 kilometers, and this figure will probably increase to 250,000 kilometers in ten years.

By the way, fuel cells have nothing to be ashamed of when it comes to driving pleasure. When we let journalists drive the B-Class F-Cell, we often hear the following comment — and I quote: "This car is awesome." All I can say to that is: "You're right."

My main message so far is therefore that if the fuel cell is going to be successful on the market, it will have to outperform the combustion engine. In my opinion, we're on track to achieving this goal. This may be a little over the top, but I can't resist saying that the fuel cell can do almost anything — except produce emissions.

4 How Much Does a Fuel Cell Vehicle Cost?

After hearing about what fuel cells can do, customers will want to know how much all of this is going to cost them. So let's not pull any punches: It's going to cost a lot — at least for the time being. A kilogram of hydrogen sells for only eight euros and will allow you to travel around 100 kilometers. That roughly corresponds to the price range of gasoline or diesel fuel. Moreover, just by using the hydrogen produced as a waste product in the chemical industry we could power 750,000 vehicles. So the problem is not the fuel price but the hardware — by which I mean the cost of the fuel cell system. On the other hand, 120 years ago the first automobiles were also much more expensive than horse-drawn carriages, in terms of both procurement and upkeep. That's why cars didn't dominate the mobility market until they were mass-produced. Similarly, the cost of a fuel cell will decline not only as a result of technological advances but, more importantly, through the achievement of economies of scale.

That's why I'm so pleased to see other automakers besides Daimler moving ahead with fuel cell technology. I'm also optimistic that the list of such manufacturers will soon grow longer. After all, fuel cell vehicles in particular have the potential to achieve a critical mass in the near future. That's because the vehicle isn't just suitable for urban applications; it's an all-rounder. And it can be used to power large passenger cars, vans, and buses. The potential fuel cell market is therefore larger than the market for battery-electric vehicles. At Daimler, we believe we can reduce the price of fuel cell passenger cars to the hybrid level in the medium term, starting from an annual production volume of 100,000 units.

Modularization is a key lever that will help us to rapidly achieve high production volumes and thus lower prices. We're already showing how this can be done with our BlueZERO label, which encompasses three different models that are based on the platform used for the A-Class and B-Class. The models are: the battery-electric BlueZERO "E-Cell," the BlueZERO "E-Cell Plus" with a range extender, and the BlueZERO "Fuel-Cell." This year the F800 Style also demonstrated that a fuel cell package can now be fitted into the vehicle architecture of a traditional sedan without the need for a sandwich floor. If you ask me, the F800 Style is the most attractive fuel cell packaging to date. Alongside modularization, the technical side of the equation also has huge potential for cost reductions. For example, it may be possible to lower the platinum content in fuel cells from 0.9 grams per kilowatt to 0.2 grams by 2020. That would correspond to the platinum content of a state-of-the-art diesel catalytic converter.

Of course, I'm not the first person to predict a major breakthrough for fuel cells in the automotive industry. Many experts have predicted the same thing at past WHEC events. I therefore want to state very clearly that it will take some time before fuel cell vehicles can be manufactured in large volumes and offered at competitive prices.

If this is to happen sooner rather than later, governments will have to firmly commit themselves to a hydrogen economy. The electric mobility summit held by Chancellor Angela Merkel here in Germany two weeks ago sent out a positive signal. But this summit must be followed by actions. I think there are three key points to be considered here. First, research must be supported in a targeted manner — not just by providing more money but also by improving the links between existing programs. Secondly, the market must be given a boost — for example, the public sector could purchase more fuel cell buses. Finally, we need to have mandatory standards, especially for the fueling station infrastructure.

Which brings me to my final question: Where do you refuel a fuel cell car?

5 Where Can I Refuel My Fuel Cell Vehicle?

There's a good anecdote in relation to this question — one that you probably already know. A little girl asks her grandfather, "Hey, grandpa, did you have computers when you were young?" The grandfather replies, "No, we didn't have computers." The girl then asks, "So how did you get on the Internet?" This story reminds us that many innovations require certain preconditions. Without computers, there's no Internet — and without a hydrogen infrastructure there will be no fuel cell cars. Only about 200 hydrogen fueling stations are currently in operation worldwide. Thirty of these are in Germany — but only seven are accessible to the public. However, customers will only accept fuel cell cars if there is a comprehensive refueling network. If there isn't, a zero-emission hydrogen car will be as much fun as an iPod without any iTunes.

One thing is clear: This "chicken-and-egg" debate will get us nowhere. That's exactly why we launched the "H2-Mobility" initiative last year in conjunction with the German Ministry of Transport and partners from the energy industry. Our goal is to establish a nationwide hydrogen fueling station network in Germany in three phases. The first phase began in 2009 with the construction of fueling stations in large cities. In 2012 we will begin establishing a network of stations on the roads that connect major metropolitan areas. A gradual further expansion will then be initiated in 2013. Eventually there will be 1,000 hydrogen stations throughout the country. I'm sure Professor Reitzle will have plenty more to tell you about the hydrogen infrastructure later on. For now, let me just say that we expect the undertaking to cost €1.7 billion. That's a lot of money, there's no doubt about it. But it's also money well spent. Moreover, raising such a large amount of money won't be a major problem if the right partners from government and industry get together. That's why I'm feeling more and more optimistic about the infrastructure issue. In addition, every fueling station built will make hydrogen more attractive to car buyers.

6 Conclusion

When you get right down to it, there are many reasons for believing that the time is right for fuel cell vehicles. Technologically speaking, we're now able to offer customers effective solutions. In terms of costs, we're making tremendous progress, and we're also finally starting to move ahead with the infrastructure.

So in my view, the question is no longer whether the fuel cell will offer an acceptable alternative to the combustion engine; the question is when this will happen. In any case, Daimler plans to continue driving developments in this field. There's a great quote from Thomas Edison that really fits in well here. Edison said, "Failure is just an interim result. Those who keep trying can't avoid being successful eventually." I think we've had our share of such "interim results" in pursuit of our goal of establishing a hydrogen economy. However, I'm also convinced that we will be successful in the end and that many of us will eventually be driving with hydrogen.

You, ladies and gentlemen, are driving this development. And it is your work and your ideas that will make the difference. You are playing a major role in shaping the future of the automobile. That's why I hope that you — and all of us — will have enough patience. For now, however, I wish all of you an interesting and successful World Hydrogen Energy Conference 2010.

Thank you very much!

On the Right Path – "All Systems Go" for Hydrogen Infrastructure

Prof. Dr. Wolfgang Reitzle, Chief Executive Officer of Linde AG, Munich, Germany

1 Summary

In his speech, Wolfgang Reitzle describes the dawning age of hydrogen as the third, "green" industrial revolution. Thanks to its unique properties and advantages, hydrogen is the logical next step in the "decarbonisation" of energy supply and personal mobility. It is the only fuel that can deliver everyday mobility from renewable and sustainable sources, and give cars sufficient range and the flexibility of rapid refuelling. The technology is there, but widespread introduction requires the collaboration of all players. The H_2 Mobility initiative, including Daimler and Linde, among others, will play a major role in this process. The partners are committed to build an infrastructure of hydrogen filling stations that will be sufficient to supply the first series-produced cars with fuel cells that will hit the market from 2015 onwards. Linde will support this growing infrastructure by delivering the enabling technologies such as high-pressure cryogenic pumps and ionic compression systems. At the same time, Linde is working toward the generation of hydrogen from renewable energy sources such as the sun, wind and regenerative raw materials or biological waste. Moreover, this environmentally friendly technology is a growth market and a source of new jobs.

2 Speech

Dear Minister-President Dr. Rüttgers, Dear Minister Dr. Ramsauer, Ladies and gentlemen,

I would also like to extend the warmest welcome to the World Hydrogen Energy Conference 2010 here in Essen.

I would like to start by quoting a study conducted by the Stanford Research Institute:

"Hydrogen would not be likely to gain favour until fuel options more compatible with existing corporate, societal and governmental institutions have been exploited and, perhaps, nearly exhausted. The reason is that a transition from our present gasoline system to a hydrogen system would require an enormous degree of effort, expense and coordination. It would be no minor evolutionary change, but the overturning of the existing system by one that was entirely new - a revolution, in short."

As you can probably imagine, these sceptical projections are not recent. They date back to 1977. And since then, we have experienced numerous revolutions and watersheds across socio-political, economic and technology milieus.

We also live in a time of change. The fossil fuel age, as it came to be known, is drawing to a close. One of the biggest challenges facing society is the need to tap new, zero-carbon sources of energy and build up a low-carbon economy. So are we on the brink of another revolution?

Well, I certainly think so. Over the next few decades, we will see a series of radical changes, driven by the third, “green” industrial revolution. To meet the challenges of our times, we will be called upon to make far-reaching decisions over the next few years.

As an engineer, I can say to you today that I am convinced we can solve the energy problem!

- We have the right technologies,
- they work in real life,
- they are affordable,
- and they will change our world – following in the footsteps of the steam engine, electricity and the Internet.

There are many reasons why I feel so optimistic. Hydrogen is definitely one of them, because it is the source of energy with the greatest potential for the future. We can manufacture it from any primary source of energy, store it safely in a format that fits individual needs and combust it as a fuel without releasing any harmful emissions. As such, hydrogen is redefining personal mobility – which is one of the cornerstones of our modern and open society.

Just as the Internet changed the world of IT by giving any-time, any-place access to knowledge to everyone, a global, hydrogen-enabled energy network has the capacity to become a defining milestone on the journey towards a global society.

But I have skipped ahead to the end of a long story that started out with the quest for energy. The decarbonisation story if you like. A tale of how wood, coal, oil and gas were turned into hydrogen. A chain of events that can be likened to the IT story, which started out with Moses and the stone tablets, moving on to the first printing press and the telephone and culminating in the virtual world of the computer.

I suppose that is what we would call the big picture. Now I would like to zoom in on what is happening today. Where exactly are we – in the year 2010 – in this great, extended development chain?

My view is that we are right at the start. No more – and no less either. The point is, we can make change happen now – if we want to, that is. Yet we must all want to. That is the true crux of the matter.

Success hinges on effective networking across all branches and levels of industry, science and politics. And the WHEC here in Essen is an excellent example of how that collaboration can work.

For me there is no doubt – if we want to move ahead quickly, we must strengthen these ties and network more efficiently. What we have often seen in the past is the art of passing the buck. And this has gone on for too long. It is the classic chicken and egg scenario. Everyone is expecting someone else to make the first move – and everyone has become very skilled at justifying their inaction. This is why I am particularly happy that this problem is being tackled and resolved on at least one front – and a very important one at that. I am referring to the new hydrogen infrastructure for cars. In Germany, we already have a few dozen hydrogen stations in operation. A couple of these are operated under the umbrella of regular, public filling stations. This makes Germany the absolute pioneer in Europe.

In acknowledgement of progress in this area, the H_2 Mobility project recently received an award. And rightly so, it is a major landmark on the path to a nationwide hydrogen infrastructure in Germany.

Last year, the H_2 Mobility project was kicked off by Daimler, EnBW, NOW, OMV, Shell, Total, Vattenfall and The Linde Group. At this point, we can say that the first series-produced cars with fuel cells will be seen on Germany's roads in 2015. The automotive industry has committed to that target.

And these cars will be able to refuel at one of the stations in the German hydrogen network. Oil and energy players – The Linde Group included – have committed to that target. Building on this initial commitment, the density of the German refuelling network will then increase, in synch with the number of hydrogen-powered vehicles on the road.

Linde has more than 100 years of experience in the industrial production, transport and varied application of hydrogen. We are the largest engineer of hydrogen plants and the world's leading supplier of hardware for hydrogen refuelling stations, which partly accounts for our optimism at the dawn of the next hydrogen chapter. A solution has been found to the infrastructure problem – in particular the basic challenge involved in refuelling hydrogen-powered vehicles. H_2 Mobility has paved the way for cost-effective expansion of this infrastructure.

We are supporting this growing infrastructure by delivering the enabling technologies such as high-pressure cryogenic pumps and ionic compression systems. Combined, these innovative products and processes give drivers a full tank of compressed gaseous hydrogen at 700 bar in just three minutes. In addition, they cut maintenance effort and thus help to further reduce the cost involved in constructing and operating hydrogen refuelling stations. In Germany alone, a further two public refuelling stations featuring these technologies are set to open in Berlin and Hamburg by the start of next year.

However, ladies and gentleman, we are very much aware that the secure, cost-efficient storage, transport and delivery of hydrogen is just one side of the story. We also realise that "green" hydrogen is the way forward. Current conventional methods of producing hydrogen from natural gas and other fossil fuels can already reduce CO_2 emissions along the entire value chain (from well to wheel) by up to 30 percent. Nevertheless, we are working toward another long-term objective – the generation of hydrogen from renewable energy sources such as the sun, wind and regenerative raw materials or biological waste.

And there are already promising concepts and concrete projects for all of these scenarios. Just take our new pilot plant in Leuna, for example. It produces hydrogen from glycerine, a by-product of bio diesel manufacture. Powering vehicles with hydrogen produced in this way cuts carbon dioxide emissions by up to 90 percent per car compared with conventional fuels. Furthermore, glycerine produced from biogenic substances does not impact food production.

And that is just one concrete example of a project generating "green" hydrogen – the list of possibilities is almost endless. Our engineers and scientists are working hard to develop innovative, viable concepts aimed at a sustainable hydrogen supply. As we move forward, hydrogen will also be used to store energy gained from other renewable sources.

If we combine conventionally manufactured and surplus hydrogen with new, innovative processes for regenerative sourcing, we are looking at a secure flow of hydrogen. In short, hydrogen is getting ready to make its mark. It is the only fuel that can deliver everyday mobility from renewable and sustainable sources, and give cars sufficient range and the flexibility of rapid refuelling.

Yet hydrogen's success also hinges on a concerted approach and support from political circles. The H_2 Mobility project is a prime example of how industry and politics are working towards a common goal. Under the umbrella of this project, companies from different industries have joined forces to advance hydrogen technology with support from the German Federal Ministry of Transport. The Federal Government has issued a clear statement to this effect: "Our goal is to establish a nationwide hydrogen network that will enable the introduction of series-produced fuel-cell cars across Germany by 2015."

However, here at The Linde Group we firmly believe that the dawn of a new energy era cannot hinge on one technology alone. We must support *all* developments aimed at helping us realign our energy base. It is therefore not a question of securing political support for fuel cells *or* batteries *or* bio energy. We need to garner support from politicians and society as a whole for *all* of these alternative sources of energy. In order to move forward, action needs to be taken on a number of fronts. We therefore believe that the current move toward wide-scale promotion of electro mobility is a step in the right direction and one that should be pushed faster than has previously been the case.

Ladies and Gentleman, Victor Hugo, was right when he said "All the forces in the world are not so powerful as an idea whose time has come." And hydrogen's time has come. After decades of research, development and testing, we now know that hydrogen technologies work, that they are affordable and capable of widespread deployment, and that they also enjoy broad political support.

The green revolution is just around the corner and I am certain it will come faster than many of us today expect. This is because it makes sound economic sense. Environmentally friendly technology is a growth market and a source of new jobs. The additional investment required to achieve climate protection and energy policy objectives will create around 500,000 jobs by 2020 in Germany alone.

In other words, the green revolution not only heralds the dawn of a new energy era and a solution to the climate catastrophe, it also promises to be an engine for growth and prosperity.

I personally see this as a huge opportunity. And if the considerable interest shown here in Essen is anything to go by, I am certain that we will make the most of this opportunity – right here and right now.

Thank you very much for your time and attention.

Summary and Outlook of the WHEC 2010

Prof. Dr. Jack Fletcher, University of Cape Town, South Africa

For this presentation, I was asked to present a synopsis of the proceedings and discussions surrounding the 18th World Hydrogen Energy Conference. In agreement with the Conference Chairperson, Professor Detlef Stolten, we agreed to attempt to identify highlights in terms of progress (developments since the previous conference in Australia) and, potentially, the impact of these in terms of near-term prospects for when we next meet in Canada.

WHEC-18 encompassed some 2200 participants (scientific delegates, exhibitors, students and scholars), approximately 330 papers, 240 posters and 150 exhibitors at 70 stands, with the scientific programme organised into 49 themes in 10 parallel sessions and, I dare say, an accurate assessment of the Conference at this point is no simple feat. Consequently, whilst I will rely on my own impressions from the plenary day, it has been necessary for the technical sessions to consolidate the views of the session chairs and importantly, given the limited time, to constrain my comments to a few prominent positions. In many ways, I am acting here merely as reporter for the session chairs and I wish both to acknowledge their contributions as well as thank them for their role as chairs, without which WHEC-18 could not have proceeded in the patently professional manner that it has.

Going back to Monday in the plenary session, my overwhelming impression was one of excitement, enthusiasm and commitment - in a way that strikes one as a step-change in the implementation of hydrogen energy and fuel cell technologies. This conclusion derives from the contributions of all the key sectors necessary for such an ambitious new technology roll-out, namely from central and local government, from the key industrial corporations as well as from the community of users – us, the public.

Specifically, Germany has committed itself as part of the Hydrogen Mobility Programme to set up a national hydrogen infrastructure grid by 2015. Starting this year within cities, progressing in 2012 to a network between cities and, in the period 2013 – 2015, to a minimum national grid comprising approximately 1 000 hydrogen fuelling stations, this is to be undertaken with a commitment of some 1,7 billion Euro. What is important about this 2015 objective is that it is concrete, it has short-term deliverables and that it is currently already in progress. In other words, this is not another general statement about the future, but rather a most immediate programme about now.

And speaking of NOW, the German National Hydrogen and Fuel Cell Technologies Programme, it is critical to note that also in 2010 the greater Europe is considering a continent-wide extension of the German programme. We also learned of the German-Japanese agreement between NOW and NIDO to exchange information in the field of hydrogen technology – an exchange in support of these implementation programmes. Likewise, we have learned of the Japanese programme for hydrogen fuelling roll-outs and, indeed, also of a similar programme in the United States, the latter both with 2015 targets. In the case of California, here too it is important to take note of the immediate near-term objectives, namely 7 additional refuelling stations under construction in 2010/11 with an additional extension and upgrade of 4 refuelling stations, such that by 2012 some 400 - 500 private vehicles would be in service. Moreover, the programme comes with the anticipation of a further 10-fold increase in the serviced vehicle fleet by 2015.

These key initiatives confirm an acceptance of the need to provide hydrogen fuelling infrastructure as the key imperative to effect a substantial roll-out of hydrogen technologies. In my view, these developments, together with the excitement and commitment with which they are being prosecuted, represent the single most significant development since the Australian WHEC meeting and one which in many ways may possibly in future be seen as the watershed event for the commercialization of hydrogen energy and fuel cell technologies. Indeed, in the words of one the session chairs, the mobile / vehicle application, which has long been seen the pre-eminent embodiment of hydrogen technology, is once again returning to the fore-front of the field, perhaps after some years of hiatus.

Whilst still on the subject of vehicles, it may further be argued that the battery versus fuel cell competition is to a large extent becoming resolved, with batteries being preferred for short-range (perhaps up to 100 km) applications but, importantly, with fuel cells clearly the only current opportunity for a full substitution of existing passenger vehicles. Consequently, the associated hydrogen fuelling infrastructure will likely be implemented in a semi-decentralised fashion as is the case for hydrocarbon fuels. Importantly, battery and fuel cell embodiments are not competitive but, rather, complementary - both being electric vehicles and, consequently, both requiring similar balance of plant such that they are synergistic and their parallel implementation will, through economies of scale, support an overall reduction in cost barriers for both vehicle types.

Fuel cell vehicles have been fully demonstrated and the implementation of the large hydrogen refuelling networks already discussed will now realise a concomitant return to a focus on cost reduction, in particular as brought about by the expected large increase in the numbers of vehicles manufactured.

Taking the German roll-out as an example, the roughly 2 billion Euro required for a national 1 000 station network is expected to support a million vehicles, such that the per vehicle capitalisation of 2 000 Euro will represent less than 10% of the average vehicle cost, again indicating that the cost of introducing hydrogen vehicles is already well within practically managed values and further improvements will readily be forthcoming as a consequence of these networks. Likewise, technical developments, e.g. the well-demonstrated and accepted 3-minute refuelling cycle, have already made the technology practically acceptable to the public.

But it is not only in the case of vehicles that significant mile-stones are being reached. Many stationary applications have been in the field for a long enough period that reliable performance data is available both for improved system costing as well as for directing performance, life and cost improvements in existing hydrogen technologies.

At a very basic level, non-precious metal catalysts, in particular those of the Ta-carbide/nitride/oxide type, may now be considered possible competitors to conventional PGM catalysts for the oxygen reduction reaction in PEM fuel cells, and it may surely be expected that this development will a substantial issue when the Conference next meets in Canada.

Solid oxide fuel cells of up to 250 kW have logged 30 000 hours. Smaller 1 kW systems in a field study of 45 units have logged a collective 250 000 hours. The European CALLUX Programme is rolling out some 800 units and good progress is being made towards the commercialisation of other unique applications, e.g. jet fuel processors and fuel cell auxiliary power units for aircraft applications. It is to be expected that, by the 2012 WHEC meeting, commercial SOFC products for distributed power generation may well be in the market.

The focus in hydride storage systems is by some considered to be moving away from materials towards engineering issues, a move - if it is true - which may suggest that the existing materials, though not perfect or necessarily close to the desired target performances, are already sufficiently attractive that implementation rather than continued research seems to drive developments. Here too, novel or niche applications such as the implementation of hydride systems, not for storage but for cooling purposes, are starting to see the light of day.

In the general field of hydrogen generation a number of trends are becoming apparent. Practicable technologies for sustainable or green hydrogen production are forging ahead via a number of alternative routes such that, by 2012, we may expect a substantial bedding down of a few practical and robust embodiments.

PEM electrolysers are approaching 100 kg/day capacities with an expectation that perhaps already by 2012, the Canadian Meeting may well hear reports of 500 kg/day PEM electrolysers. Similarly, substantial progress is being made in the greening of fossil hydrogen generation technologies, including also a range of hybrid generation systems with or without electrolysis steps, the aim of which is an improved overall energy efficiency and consequent reductions in capital and operational costs. Also, in the field of high temperature electrolysis, it has been demonstrated that the use of planar cells is feasible.

It has further been suggested that, in the arena of thermo-chemical water splitting for large scale hydrogen production, the hybrid sulphur process is beginning to show evidence for a clear leadership position in terms of early implementation. In this regard several developments, including improved membranes and catalysts for sulphuric acid splitting, and silicon carbide heat exchangers for overall cycle containment are adding greatly to the pace of development.

Well, it has been a long week and I don't wish to belabour you at this hour with further details. In closing, I wish to return to something else from first day which in my view represents a crucial change of emphasis in the manner in which hydrogen energy and fuel cell technologies are being viewed. In addition to a route to environmental protection, to the amelioration of climate change and the reduction of oil consumption – all well-established drivers for a hydrogen economy - it is important to note in both the US Department of Energy programmes and in the German Hydrogen Mobility Programme, that there are clear business / industrial / employment imperatives such that hydrogen energy and fuel cell technologies are increasingly driven by factors of economic gain and opportunities for employment. Indeed, this has become a key driver for the German Ruhr area in which we find ourselves today - to re-invent itself, still as a world industrial centre and exporter of engineered goods, but of the new hydrogen technologies, the NOW way forward. At this time, when the hydrogen infrastructure deployment programmes of several nations are being implemented, we of the hydrogen community are to take pride in the successes already achieved such that we may re-invigorate our efforts to master and perfect a hydrogen energy future.

Borrowing from another presentation, I can say its HY-time and that, at least in Germany, the time is NOW!

I thank you for your indulgence...

Potential of the Chemical Role of Hydrogen

Jean-Marie Solvay, Solvay, Brussels, Belgium

1 Summary

This paper reflects on the potential of the chemical role of hydrogen in the emerging early market applications within the field of fuel cells. Examples of the main polymer electrolyte membrane (PEM) fuel cell applications and of first products are presented together with some of the main players of this industry in an early development phase.

Due to the early stage of the market development, the role of innovation is discussed briefly: Technical innovation as a strict increase in performance is estimated to be more critical for the automotive fuel cell development with extremely stringent performance, durability and cost targets to compete against an existing and widely established technology.

Innovative business solutions are also needed to create traction in early market fuel cell applications that already meet the specific requirements of their niche markets. This business development activity is essential to establish, in the short term, the fuel cell technology as a credible alternative to traditional power supply.

Solvay [1] as a provider of specialty polymers together with Umicore [2] – a company specialized in catalysis and precious metals recycling – and their Joint Venture SOLVICORE [3] provide innovations, material and component solutions for the early market fuel cell applications of today and automotive fuel cell technology of tomorrow.

As governments around the globe are funding fuel cell development, in some cases, with very large resources, we may be on the verge of a quickening of market developments in some areas to be closely watched. The main activities are mentioned together with some of the principal industrial players and their regional spread.

2 Introduction

Hydrogen is widely seen as an important and clean energy carrier of the future [4]. Today hydrogen is mainly used as an industrial gas for chemical processes. The main production method for hydrogen is steam reforming of natural gas, in which by means of a catalytic reaction hydrogen is extracted from methane with CO_2 as the main by-product. Other ways to generate hydrogen are the widespread chlorine-alkali electrolysis reaction or polymerisation processes, in which hydrogen is released as a waste product. Therefore the main production sites for hydrogen are refineries and chemical plants. As hydrogen is used as a chemical gas also in other processes (e.g. reduction of metals), there is an industrial market with well established players such as LINDE (Germany) [5], AIR LIQUIDE (France) [6], AIR PRODUCTS (USA) [7] or IWATANI (Japan) [8].

With the increasing popularity of fuel cell technology over the last 10 years, the interest in hydrogen generation, infrastructure, storage and transport increased dramatically. Fuel cell driven vehicles or products will not be successful without the required hydrogen infrastructure and efficient ways to produce, transport and store hydrogen. One promising technology to produce hydrogen on demand from electricity is the reverse fuel cell or the so called PEM electrolysis. This technology offers the potential to produce hydrogen without any greenhouse gas emissions when it is combined with electricity from renewable sources [9].

In September 2009, the leading vehicle manufacturers in fuel cell technology - Daimler AG [10], Ford Motor Company [11], General Motors Corporation [12], Honda Motor Co., Ltd. [13], Hyundai Motor Company [14], Kia Motors Corporation [15], the alliance Renault SA [16] and Nissan Motor Corporation [17] and Toyota Motor Corporation [18] - issued a joint statement to the development and market introduction of electric vehicles with fuel cells [19]. This statement predicts the introduction of several hundred thousand vehicles in the years after 2015. Only one day later Daimler, Linde, Shell [20], Total [21], Vattenfall [22] and others signed a Memorandum of Understanding (MoU) together with the German authorities to establish a hydrogen infrastructure in Germany after 2015 [23].

Though the path for the commercial introduction of electric vehicles with fuel cells and the related hydrogen infrastructure seems to be clear, it will still require another five to ten years until this market will slowly emerge.

Until then, there are other interesting activities in the field of fuel cell technologies, which will be discussed in this paper. As the first so called early fuel cell markets already exist in several niches, several thousands of fuel cells are in the hands of consumers or industrial users today [24]. In early market applications the products are targeting specific competitive advantages, such as the reduction of system operational costs, increase of battery runtime or green minded consumer habits. These early markets and some of the relevant players are presented together with the potential of the technology for the specific niche market and its challenges.

3 The Emergence of Early Application Markets within the Field of Fuel Cells

The early application markets can be divided into four main groups of applications:

- alternative propulsion
- portable fuel cells
- stationary combined heat and power production (CHP), auxiliary power units (APU) and uninterrupted power supply or back up power systems (UPS)
- hydrogen generation via PEM electrolysis

Solvay and its Joint Venture SolviCore (Joint Venture with Umicore) provide innovations, material and component solutions for the above mentioned early market fuel cell applications of today.

3.1 Alternative propulsion

The drive train concept of fuel cell vehicles will not be a 100% fuel cell solution, but a hybrid concept which will combine the fuel cell as power generator and supply, a battery as power storage and supply and the electric engine to drive the vehicle [25]. For the classical automotive application the operational mode and the size ratio between fuel cell and battery are still under development. Nevertheless, it is expected that the fuel cell has to operate most dynamically to answer the requirements of the standard automotive drive cycles, which include start and stop routines under various condition. As this application will require further development time until commercial products will enter the markets, it will not be discussed here.

The situation is different for the so called “Alternative Propulsion” concepts. In these applications the achievements of the fuel cell development of the last decade and its advantages were combined with hybridization concepts and specific requirements of specialty vehicles such as buses, duty, specialty and material handling vehicles, boats and other light vehicles, which already used hybrid or electrified drive trains. For the early markets in this field, specific advantages of the integration of fuel cell technology lead to new clean solutions that in several cases also provide cost advantages during operation [26].

The number of fuel cell hybrid buses that were tested in the last years and are under operation today is constantly increasing and probably number above 100 today. Leading companies here are: TOYOTA and DAIMLER with their HINO [27] and CITARO [28] bus fleets which are operated in Japan, Europe and in the USA. Other bus manufacturers such as VAN HOOL [29] in Belgium are also testing fuel cell hybrid concepts by integration of fuel cells from stack manufacturers such as UTC [30].

The operation of fuel cell buses has many advantages: the infrastructure issue for hydrogen can be solved by a central filling station, the volume and weight of the hybridized drive train concept is carried by the large vehicle, the vibration and noise for the passengers are reduced, additionally, the buses are operating with zero emissions to the environment.

Tractors, garbage trucks, trains or other specialty vehicles basically have similar characteristics as discussed above for buses. Partnerships were developed between vehicle manufacturers and fuel cell companies to integrate the fuel cell hybrid concept into these vehicles. One example is the European initiative HYCHAIN [31], where under the lead of AIR LIQUIDE, fuel cells from its subsidiary AXANE [32] or other manufacturers were integrated into small transport or utility vehicles.

A success for the introduction of fuel cell technology into an existing market is the replacement of lead-acid batteries in the area of material handling. Especially in the USA large amounts of public funding money enabled forklift manufacturers such as YALE [33], RAYMOND [34], HYSTER [35] or CROWN [36] to integrate fuel cell systems from BALLARD/Plug Power [37, 38], NUVERA [39] or HYDROGENICS [40] to build several hundred forklifts and to set up their operation at several sites across the USA. The advantages are zero emission of the trucks, fast refuelling, less battery maintenance and charging time, which means more efficient operation of the truck fleet.

Activities in Europe in this field are taking off more slowly. Currently partnerships between European forklift and fuel cell manufacturers are in the early phase (e.g. HYDROGENICS and STILL [41]) and there is not yet a comparable funding activity to support the establishment of a European technology platform. In Japan TOYOTA and NISSAN already have been operating their own fuel cell technology in their forklifts since many years and started to announce the commercial introduction of their future products [42, 43].

The large boat and yacht market is a very interesting field for the clean and quiet fuel cell technology. Starting from CO_2 emission regulations for harbour manoeuvres to the reduction of noise and vibration of diesel gensets, that are used today to supply the boats with electricity, the advantages of fuel cells are obvious. One example for the integration of fuel cell technology into a sailing yacht is the ZERO-CO_2 YACHT project [44]. A hydrogen fuel cell that was developed in collaboration between PSA and the CEA is integrated into a sailing yacht from the boat manufacturer RM to provide the electricity for the electric engine of the yacht and eventually for the research lab, which is used during the research expedition to study pollution in the Mediterranean Sea. Another example is the development of generator type fuel cells by the VOLVO [45] subsidiary POWERCELL [46]. As one of the world's largest manufacturers of marine engines and generators, VOLVO is developing its market to the next level by reduction of emissions, noise and vibration.

The market for light vehicles is huge as it covers a broad range from leisure electric bicycles, scooters to medical wheelchairs or utility transport vehicles. These markets were also addressed in the European HYCHAIN program, in which e.g. AXANE fuel cells were integrated into electrical wheelchairs.

In all these areas of alternative propulsion it has been demonstrated that fuel cell technology can provide clean solutions together with economical feasibility. With increasing production volume and the expected cost reductions it is expected that these markets have a strong growth potential in the coming years.

3.2 Portable fuel cells

Portable electronics created several revolutions in people's lifestyle over the last decades. Portable music, video players, cameras and game consoles merged into smartphones, the latest mobile communication devices. People today are used to the support of electronic devices, but also to the necessity of chargers and charging times. At the same time, many technologies adopted electrical features or require electricity for their operation. Sometimes the power demand is served by large batteries, sometimes by small generators, which are often called Auxiliary Power Units (APUs).

For all these applications fuel cells can provide either more comfort, less weight or noise and emission free solutions, which in specific niche applications also reduce the operational costs dramatically due to reduced maintenance requirements.

The APU fuel cell market already exists. Though based on methanol as a very high density energy source – not based on hydrogen – the German company SMART FUEL CELL [47] has developed a range of portable power generators in the range of several hundred Watts. The portable generators are marketed under the name Efoy as APUs for recreational vehicles, as portable generators for remote electricity supply and as battery range extender for light electric vehicles. A similar product also serves as APU or generator for marine applications under the name MAXPOWER [48]. More than 15.000 of these units are in operation today while the market and the volume are constantly growing.

The introduction of the fuel cell as a battery runtime/range extender for long term low Watt power supply is the goal of the German company FWB [49]. Again methanol powered fuel cells are combined with a battery to utilize the high energy density of methanol inside of a tank to power towel machines, sensors or UPS tracking devices. These devices require very low level power supply in the Watt range over a time periods of several weeks or even months. Today the solution is the use of large batteries which cause very high operational or maintenance costs.

The introduction of small battery chargers for Li-Ion batteries based on methanol fuel cells was not successful over the last 10 years due to the limitations of the power density of the fuel cell systems. In 2010 the Swedish company myFC presented a tiny battery charger, which is supposed to hold enough energy and supplies sufficient power density to charge Li-ion batteries [50].

In the areas, in which limitations of battery runtime or long charging times are the cause for limitations to the use of portable electronics or any battery dependent device it has been demonstrated that fuel cell technology can provide clean and comfortable solutions together with economical feasibility. With increasing production volume, the expected cost reductions and increasing customer acceptance it is expected that the fuel markets will grow together with the markets of their applications.

3.3 Stationary CHP, APU, UPS

A fuel cell development program was started in Japan in the 1990s with the goal to supply private households with heat and electricity generated by residential fuel cell units. These units combine a reforming unit to convert a methane rich gas into a hydrogen rich gas, which is again transformed in a fuel cell into electricity and heat for the hot water supply. During a research phase about 100 field test units were installed and operated in the years 2002 to 2005. The commercial introduction of combined heat and power supply units (CHP) based on residential fuel cells has started in Japan. In collaboration with house manufacturers more than 7000 units were installed between 2005 and 2010. The suppliers of these systems are the Japanese companies TOSHIBA [51], PANASONIC [52], ENEOS [53] and TOYOTA. Funded by a large NEDO [54] program these companies were able to develop and establish the complete value chain for the technology in Japan. It is planned to continue the introduction of these systems with increasing volume in the coming years and to explore other markets for the technology.

There are no such programs in the USA and in Europe. In the USA companies tried to develop similar systems in different sizes over the last 10 years, but no commercial breakthrough of any system could be achieved. In the frame of the German CALLUX program [55] a few hundred systems will be installed in the coming years, which will demonstrate the integration of PEM fuel cell stacks from the Canadian company BALLARD by the British company BAXI [56] among other fuel cell technologies.

The chemical industry with its large scale production of Chlorine, NaCl and various polymers produces huge quantities of so called waste hydrogen [57]. In some cases the hydrogen is used in integrated processes or for its caloric value. In other cases the hydrogen is vented to the atmosphere as its use is not required or too cost intensive for the facility owner. In 2010 SOLVAY launched a project at its Solvin plant in Lillo (close to Antwerp, Belgium) to explore the potential of the utilization of such process waste hydrogen [58]. For this purpose a 1 MW fuel cell plant from the Dutch company NEDSTACK [59] will be installed to generate electricity and hot water for the facility. Together with its Joint Venture SolviCore, that is the supplier of the membrane electrode assemblies (MEAs) for the fuel cell, and NEDSTACK as system provider, SOLVAY will investigate and demonstrate the economic and ecologic potential of the fuel cell technology to recover waste hydrogen from chemical processes to feed back electricity and to reduce the carbon footprint of the Lillo facility.

In countries with a weak infrastructure for electricity and communication fuel cells have the potential to provide safe back up power supply for IT and telecommunication centers (remote power supply). Installations for these purposes are successfully operated In the USA and in India, more installations are expected to follow in the coming years in other developing, emerging or remote areas in the world [60]. The advantages of these markets are that the technical challenges for the fuel cells are relatively moderate, which leads to simplified designs that can meet the cost targets of the application. Main players in the USA are BALLARD with PLUG POWER, IDATECH [61] and others as system integrators, HYDROGENICS and NUVERA, Main players in Europe are HELIOCENTRIS [62] and RITTAL [63] as integrator of BALLARD stacks in Germany, AXANE and HELION [64] in France and NEDSTACK in the Netherlands.

The market for APUs for trucks and buses is motivated by strict regulations for emissions during idling times (e.g. overnight). Today the electricity for the cooling of truck loads or for the truck cabins is provided by the diesel engine in idle mode. As this is causing noise, CO_2 and other emissions VOLVO, one of the large truck producers in the world, is developing fuel cell APUs with a diesel reformer in its subsidiary POWERCELL.

AXANE is also developing a market for mobile power generators. With the background of its owner AIR LIQUIDE as a gas and hydrogen supplier these systems are operated with bottled hydrogen.

Due to emission reduction programs or interesting niche applications, new markets for fuel cells are being developed. New solutions are already in the market today with growing acceptance and success.

3.4 Hydrogen generation via PEM electrolysis

While fuel cells produce electricity and water, a reverse fuel cell reaction can be used to generate hydrogen and oxygen from water and electricity. This reverse fuel cell technology is called PEM electrolysis [9]. Compared to the well established technology of alkaline electrolysis the PEM electrolysis has significant advantages for several applications. The main advantages of the PEM electrolysis are the potential for a wide operation window and the high energy efficiency which results in very compact systems with a size reduction of more than 90% compared to alkaline systems.

Until recently the main market for PEM electrolyzers was the production of hydrogen for industrial use as process gas in chemical processes, in metal treatment (reduction), in the semiconductor industry and for generator cooling in power plants. The main manufacturers of PEM electrolysis systems for the so called on site hydrogen production are MITSUBISHI CORPORATION in Japan [65], PROTON ENERGY [66] and HYDROGENICS in North America and HYDROGEN TECHNOLOGIES (STATOIL, Norway) [67] and HELION (France) in Europe. This market has been slowly growing over the last 10 years and is becoming more and more attractive as the transport of hydrogen or its storage are expensive and ineffective for the overall energy and CO_2 balance.

In the last five years the first fueling stations were tested or installed in Europe, Japan and the USA which used PEM electrolyzers for the onsite hydrogen production.

In combination with renewable energy sources such as solar or wind energy hydrogen production can be realized without any CO_2 emissions. The first company that demonstrated such a green fueling station was HONDA in Torrance, California already in 2001. In recent years the utilization of electrolysis technology in combination with renewable energies becomes more and more relevant as it is seen as a solution to transform renewable energy into hydrogen as innovative energy storage method. In addition the technology could help to stabilize the electricity network which is facing more and more fluctuating power generation profiles due to the increasing percentage of renewable energy [68]. Under these conditions the advantages of the PEM electrolysis are obvious as relatively small systems can react dynamically to fluctuation of power input and generate hydrogen with high efficiency. The hydrogen can be used afterwards either in chemical processes or to produce electricity again in fuel cells.

4 Innovation in the Field of Fuel Cell Technology

Currently the emerging fuel cell industry is still highly fragmented. This is a major hindrance since it slows down development and achievements of economies of scale. Solvay as a provider of specialty polymers together with Umicore – a company specialized in catalysis and precious metals recycling – and their Joint Venture company SolviCore are committed to provide innovation, material and component solutions for the early market fuel cell applications of today and automotive fuel cell technology of tomorrow.

Technically this means that SOLVAY will develop new polymers and membranes and at the same time UMICORE will develop new catalysts with increased performance and durability, while SolviCore will integrate these new components into its MEA technology and establish the relevant mass manufacturing processes for the growing industry.

The joint effort of Solvay and Umicore can be seen as an example of open-innovation in the emerging fuel cell industry. Both chemical companies identified their potential for synergies in the development of the critical component MEA in 2005 and started a common activity in 2006. The next step is the joint development with other component and finally with fuel cell manufacturers to increase the partnerships along the supply chain.

The 1 MW project in Lillo is such an example which also includes the joint development of a new market. As Solvay has an interest in the utilization of waste hydrogen gas in its chemical plants and an interest in using SolviCore´s MEAs, the collaborative project with NEDSTACK is an approach to develop the technology and the market together.

Another example is SOLVAY´s collaboration with the UK based company ACAL [69]. ACAL´s innovation is in the new system architecture of their stationary fuel cells. These fuel cells are similar to the PEM fuel cells but have no cathode catalyst layer. Instead of the precious metal containing catalyst layer, ACAL realizes a proton exchange on the cathode with a reaction of a chemical catalyst which is pumped through along the cathode side of the membrane

(FLOWCATH®). To support the introduction of such new systems to the market by installation of a demonstration unit at a SOLVAY plant in the UK and in a collaborative approach between ACAL, SOLVAY and SOLVICORE will be the starting point of a new market development initiative.

SOLVAY and SOLVICORE are looking for such partnerships to overcome the hurdles of fragmentation and in the interest of boosting market development. Umicore also supports the activity with the service offer to develop financing and recycling models for the precious metals that are used in the fuel cells. Being the largest recycler of precious metals worldwide and one of the important suppliers of precious metal containing materials to the industry, Umicore expects from its experience in other markets, that the high fragmentation of the players along the value chain in the fuel cell market will probably merge towards those players that already have a large experience in handling, selling and trading of precious metals on the supplier side and towards those companies that are large and experienced enough to integrate large volumes of precious metals into their products [70].

As the path for fuel cell technology introduction in the automotive industry seems to be defined for the coming 10 years, innovation will have an important role to identify new applications in which fuel cells provide an operational, comfort, emission or cost advantage compared to existing energy solutions. At the same time governments, industrial users and consumers will have to be educated and informed about the new technologies, their status and their advantages in order to accelerate acceptance.

5 Fuel Cell Activities in Different Geographical Areas

The monitoring of fuel cell activities in the different geographical areas is important because it is currently the local applications of small efficient units that will drive development. The description that follows combines the view on main industrial players, technical status of the development and governmental programs, as these three topics are highly dependant on each other.

Asia probably has the strongest efforts in the area of fuel cell technology development, as this technology is identified as a key technology for the future of energy supply in countries like Japan, Korea, China and Taiwan. Here significant amounts of money are invested into the development of the complete value chain from materials, over components to systems.

The biggest and oldest program is the NEDO funding for the development of automotive fuel cells, residential fuel cells and hydrogen infrastructure in Japan [54]. Along the complete value chain, it has developed the key suppliers to a complete industry together with a handful of leading research institutes and universities as industry support. Among these players are TANAKA (catalyst) [71], ASAHI KASEI (membrane) [72], GORE-TEX (membrane and MEA) [73], TORAY (Gas Diffusion Layer – GDL) [74], MITSUBISHI RAYON (GDL) [75] and NOK-FREUDENBERG (GDL, Sealing, humidifiers) [76] in the field of materials and components. Among the important system OEMs are PANASONIC (residential and portable), TOSHIBA (residential and portable), ENEOS (residential), TOYOTA (residential, automotive and alternative propulsion), HONDA (residential, automotive and electrolysis), NISSAN-

RENAULT (automotive and alternative propulsion) and MITSUBISHI CORPORATION (electrolysis).

More recent is the launch of a funding program in South Korea, which funds Korean companies to establish the value chain and the technologies for a new Hydrogen Economy [77]. Main players in Korea are SAMSUNG (APU, portable, residential) [78], LG (portable, residential) [79], HYUNDAI/KIA [14, 15] and GS FUEL CELL (residential) [80]. The industry is strongly supported by the two major research institutes KIST [81] and KIER [82].

China and Taiwan also have funding programs with significant volume. Traditionally in China, a lot of effort and research money are invested in universities or institutes. R&D success is quickly followed by commercial initiatives supported by the government: the creation of new companies or transfer of the technology to big Chinese players. Given the large potential of these countries, it can be expected that they will play a major role in the fuel cell and hydrogen industry of the future.

India and other emerging economic powers are still shaping their programs but are committed to support the hydrogen economy.

Europe and many European countries launched their large funding programs in the recent years. The European Joint Technology Initiative (JTI) will distribute more than 400 million Euros to the 27 countries of the EU over the next 10 years. Today it is not clearly defined if the focus of the program will be research, value chain or demonstration project funding.

In addition, main government initiatives in Europe can be seen in Germany, France, UK, Belgium, Denmark and Norway.

Each country has specific important players for the industry. In Norway a subsidiary of STATOIL (Hydrogen Technologies) has a focus on hydrogen production. In Denmark, IRD [83] covers the value chain from MEA manufacturing to complete fuel cell systems. In Belgium activities of research institutes, universities and Belgian companies active in the field of fuel cells are supported in R&D and demonstration projects. Among the industry players are HYDROGENICS (hydrogen production), SOLVAY (fuel cell demonstration, polymers, membrane) and Umicore (catalysts and precious metals recycling). In the UK funding is provided to universities, institutes and industry players that develop materials and components such as JOHNSON MATTHEY (precious metals, catalysts, membrane, MEAs) [84] and system developers such as INTELLIGENT ENERGY (alternative propulsion) [85] and ACAL (residential) with their innovative fuel cell approach. France launched the seven year H2E program in 2009 to develop their hydrogen economy at a volume of about 200 million Euros [86]. It consists of 20 French companies and is lead by AIR LIQUIDE (hydrogen supply). Other major players are PSA (automotive) [87], MICHELIN (alternative propulsion, automotive) [88], AXANE (UPS, alternative propulsion), HELION (UPS, alternative propulsion, electrolysis), ARCELOR MITTAL (components) [89] and CEA (research, system development) [90].

The German program NOW was launched in 2008, the first funding initiatives were started in 2009 [91]. The program will distribute about 500 million Euros of funding to activities in Germany over 10 years in public private partnerships. The main focus is demonstration of fuel cell technology or pre-commercial activities to develop the emerging markets, but covers material, component and system related initiatives. Main players in Germany are DAIMLER (automotive), RITTAL (UPS), HELIOCENTRIS (UPS, educational), PROTON MOTOR (alternative propulsion) [92], SFC (APU, portable), MASTERFLEX (UPS, educational, alternative propulsion) [93], BOSCH (components, valves, compressors) [94], FREUDENBERG (GDL, sealing, humidifier) [95], SGL (GDLs) [96], SCHUNK (stacks, bipolar plates) [97], VICTOR REINZ/DANA (bipolar plates) [98], SolviCore (MEAs), FUMATECH (membranes) [99] and many institutes in the different federal states of Germany.

A large initiative is executed in the USA by the Department of Energy (DOE) [100], which supports the development of fuel cell technology since many years. Main players in the North America are GM (automotive), FORD (automotive), BALLARD (Vancouver, Canada – automotive, alternative drive train, UPS, residential) with its system integrators PLUG POWER and IDATECH, UTC (automotive, alternative drive train), NUVERA (alternative drive train, UPS), HYDROGENICS (Toronto, Canada – alternative drive train, UPS, electrolysis), PROTON ENERGY (electrolysis), BALLARD MATERIALS (GDL), 3M (catalysts, membrane, MEA) [101], GORE (membrane, MEA) [73] and DUPONT (membrane) [102].

6 Conclusion

The potential of hydrogen as an alternative energy source depends initially on the development of technical efficiencies in local, targeted and innovative applications. The successful partnering of the various stakeholders will enable the production of competitive market solutions. This activity will further drive development and education on the benefits of a future hydrogen infrastructure, as a credible solution to our clean energy requirements.

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The Future is Now: Fuel Cell Technology Made in Germany

Karl P. Kiessling, VDMA Chairman Fuel Cell Working Group, Germany

Summary

Fuel cell technology is at a crucial point of its development: the advantages of the technology fit perfectly the energy challenges the world faces today and there is a furious competition between countries to develop national capabilities to produce fuel cells. Governments are moving from R&D support programs to market development programs, so that their protégés benefit from scale effects, an accelerated learning curve and means to bridge the gap with competing technologies. The Fuel Cell Working Group of the VDMA is a key player in this process as it promotes the efforts made by the numerous German players in this field. In particular, it is instrumental in making sure that the German support programs are at par with those of the two other main innovators for fuel cells: USA and Japan.

1 The Fuel Cells Working Group of the VDMA

The Fuel Cells Working Group of the German Engineering Federation (VDMA) is an industry network of fuel cell manufacturers. This working group offers the unique opportunity to jointly address the main issues of the industry as well as to define a common approach for the efficient roll-out of the technology. Its key activities are:

- Networking and sharing on business opportunities
- Systems and components optimization
- Lobbying
- Definition of market launch strategies
- Coordination of industry initiatives
- Public relationship

2 Our Goal: Tackling the Forthcoming Energy Challenge

Our societies have become extremely reliant on energy and electricity in particular. Electricity is present in every aspect of our lives, from our basic needs (e.g. lighting, refrigeration, transportation) to our more elaborate ones (TV, music etc.). This reliance on electricity has grown tremendously in developed countries through the broadening of its applications. It is poised to grow even further with the accelerating emergence of developing countries, especially China and India. Overall, it is estimated that the demand for power will grow by 50% by 2030 with India and China accounting for half of this growth.

Today, electricity is mostly generated from fossil fuels with poor efficiency. This growth in demand will therefore generate tremendous amounts of CO_2, among other pollutants.

Traditional technologies cannot be the solution to tackle this issue:

- Fossil fuels are by nature finite in quantities; supply and prices are volatile
- A few countries control the supply of fossil fuels, most are hit by the "oil curse"
- Current technologies are heavily polluting, as illustrated by the coal plants in use in China and elsewhere

Renewable energies like wind and solar cannot solve the matter either as they are dependent on the weather conditions. As a result, they need to be coupled with storage technology to provide reliability. Those storage systems are currently both expensive and use a lot of space (lakes, dams, puffers etc.).

This situation requires radical change towards clean and efficient technologies; it is the engineering industry's responsibility to develop those. Fuel cells can address part of the challenge.

3 The Promising Technology of Fuel Cells and its Development

3.1 Fuel cell industry in Germany

There are numerous players in the field in Germany, and they are working hard to make their innovative solutions ready for market applications. Within the VDMA Fuel Cell Working Group, 200 manufacturers of fuel cells systems or components are represented. Small companies account for 50% of those, while large corporations make up the rest (refer to appendix 1 for an indicative list).

Furthermore, over 60 research institutes are involved; most are highly specialized and part of a university. Together, those players represent a tremendous potential for innovation and a deep commitment to making fuel cells a success.

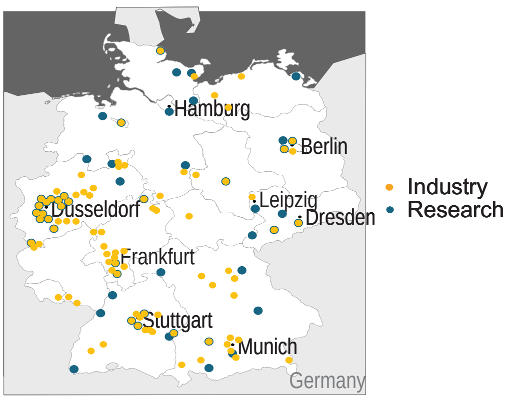

Figure 1: Locations of fuel cells players in Germany [1].

This potential and this commitment materialize in the amount of patents filed[2] and in the split of the 125 MW installed capacity of stationary applications of fuel cells. Both demonstrate that Germany is one of the leaders in the field[3].

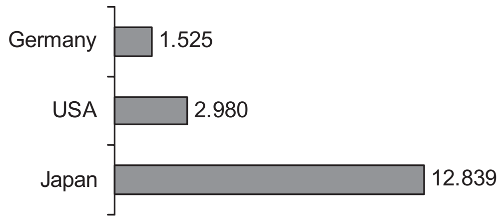

Figure 2: Number of patent filings (top 3 countries 2001 - 2005).

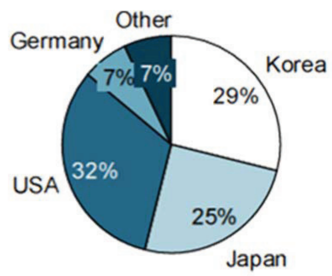

Figure 3: Share of installed capacity for stationary applications per country.

From an application standpoint, fuel cells can be split into three main categories, all of them addressed by German players:

- Special applications with a capacity ranging between 10 W and 15 MW. Those run on hydrogen or methanol and typically consist of small power generation in remote areas or in mobile uses (camping, lighting etc.)
- Stationary applications with capacities from 1-5 kW to 200 kW and above running on natural gas or biogas. They are used to produce power and heat for houses, buildings, plants, large ships etc.
- Mobile applications above 30 MW running on hydrogen. Those consist of cars, buses and trucks powering.

3.2 Technical features of fuel cells

3.2.1 Chemical principle

The basic reaction happening in a fuel cell is the reformation of water from hydrogen and oxygen:

$$2\ H_2 + O_2 \rightarrow H_2O$$

Some fuel cells run on hydrogen, which needs to be generated by an outside process, some run on gas containing CH_4. In the latter case, hydrogen is generated through an internal reformation:

$$CH_4 + 2\ H_2O \rightarrow CO_2 + 4\ H_2$$

Gas containing methane vary in origins but have all great potential. Natural gas and methanol are readily available and their supply is growing. Biogas and sewage gas are also already produced and their use is being developed.

3.2.2 A step change in efficiency and emissions

Fuel cells introduce a step change in the efficiency to turn fuels into power. The electrical efficiency of a fuel cell in the 300 kW class is comparable with a modern 600 MW gas turbine power plant coupled with additional steam turbine. This sophisticated energy solution generates new opportunities inside cities as it fits the decentralized need for heating and cooling.

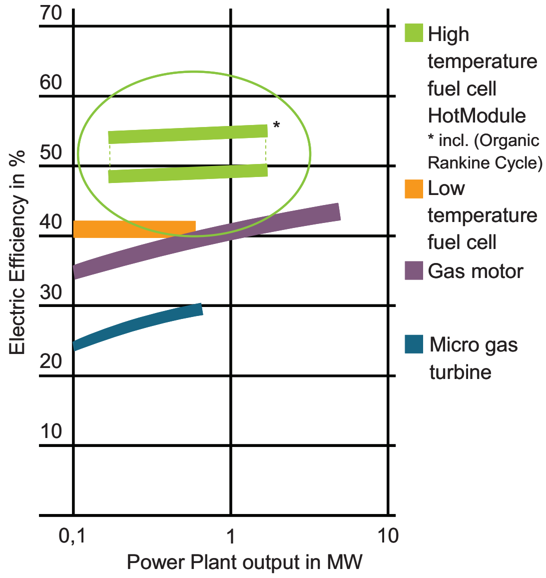

Figure 4: Comparison of the electrical efficiency of MTU's HotModule 346 kW fuel cell and conventional technologies.

As a result of this higher electrical efficiency and of the systematic coupling of fuel cells with Combined Heat and Power systems (CHP), the total efficiency (electrical and thermal) can be as high as 90%. Hence, the CO_2 footprint is dramatically smaller than the ones of all standard power producers.

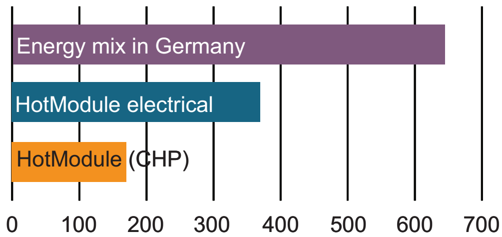

Figure 5: Comparison of CO_2 footprints (g CO_2/kWh).

Last, the nature of the exhaust is such that it is an “exhaust air” in the case of a HotModule fuel cell, to be compared with exhaust gases for all other production means. As a matter of fact, the German regulation on exhausts (TA Luft) is already fulfilled by fuel cells.

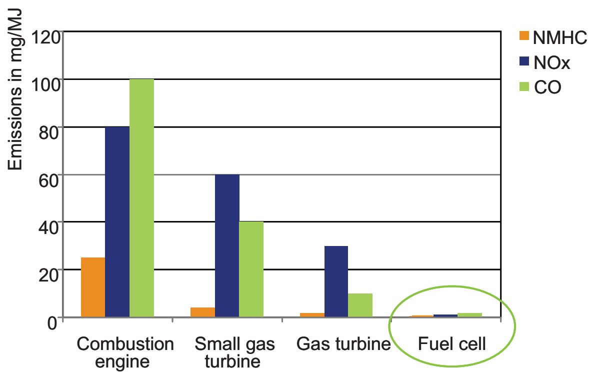

Figure 6: Comparisons of emissions for different technologies.

Table 1: MTU’s HotModule exhaust air characteristics compared with TA Luft requirements.

	HotModule*	TA Luft
SO_2	< 0,5 mg/m_n^3	350 mg/m^3
NOx	< 3 mg/m_n^3	500 mg/m_n^3
CO	< 9 ppm	150 ppm
Particulate	< 1mg/m_n^3	n/a

*HotModule CHP

4 Development Support in Germany

The industry has made significant investments in both the R&D around Fuel Cells and the facilities to grow production volumes. However, those investments need to be supported by governmental initiatives to compete with existing technologies. Those initiatives, whether through subsidies or regulations will be the stepping stones to start production in series, reduce fixed costs and accelerate the learning curve.

They a required in order to create a strong market in Germany; which the German players would leverage to export overseas.

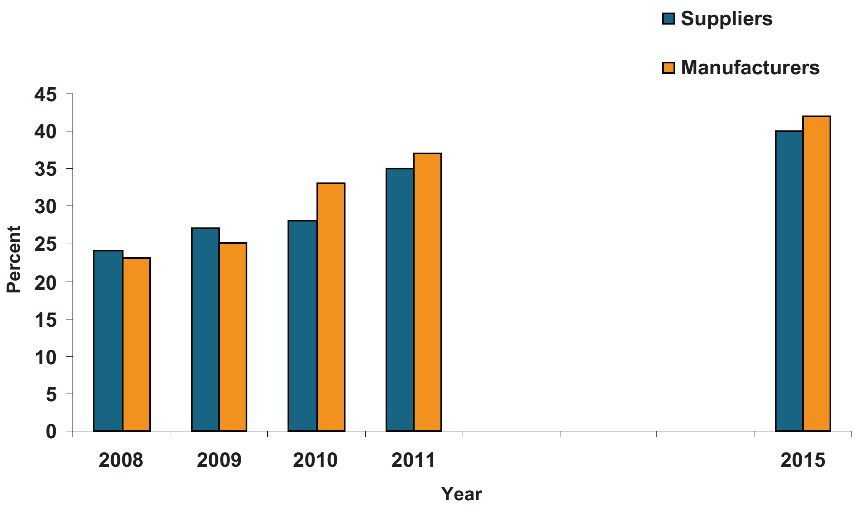

Figure 7: Percentage of sales through exports [4].

Germany has installed a fuel cell demonstration program called NIP (National Innovation Program for Hydrogen and Fuel Cell technology). However, it is a demonstration program only and does not support market deployment. Its end is scheduled for 2015; which creates substantial uncertainty. As a matter of fact, it is also clearly inferior to programs in the USA or in Japan as illustrated below:

Table 2: Comparisons of budgets for the development of fuel cells.

Jahr	DE	EU	USA	Japan
2001	19 Mio. €	36 Mio. €	126 Mio. €	157 Mio. €
2002	33 Mio. €	36 Mio. €	111 Mio. €	208 Mio. €
2003	33 Mio. €	69 Mio. €	186 Mio. €	306 Mio. €
2004	65 Mio. €	69 Mio. €	304 Mio. €	400 Mio. €
2005	65 Mio. €	69 Mio. €	402 Mio. €	430 Mio. €
2006	70 Mio. €	69 Mio. €	270 Mio. € (DoE)	260,3 Mio. € (METI)

Those programs are key as currently, the fuel cell cannot compete on a financial basis with substitutes, especially turbines or engines. The latter will generate a much higher rate of returns as they benefit from scale and 100 years of cost reductions and learning curve.

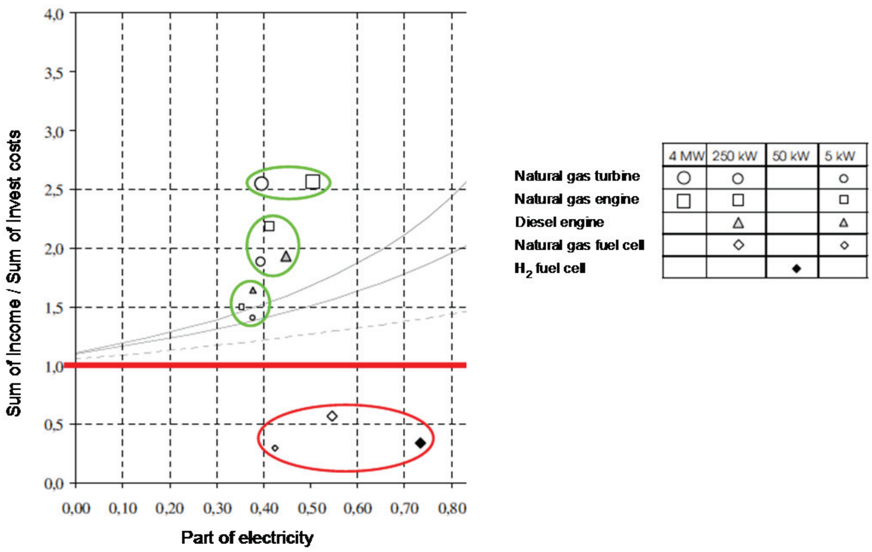

Figure 8: Compared economics of fuel cells, engines and turbines [5].

Figure 9: HotModule fuel cell HM300 at Germany's largest private brewery Erdinger Weißbräu.

Appendix

VDMA Fuel Cell Working Group Members
3M Deutschland GmbH
Baxi Innotech GmbH fuel cell heating
Bosch Rexroth AG
Bürkert GmbH & Co. KG
Buschjost Norgren GmbH + Co. KG
Das Institut für Industrielle Fertigung und Fabrikbetrieb, IFF
DEUTZ AG
DLR - Deutsches Zentrum für Luft- und Raumfahrt e.V.
Eisenhuth GmbH & Co.KG
EnyMotion GmbH
eZelleron GmbH
Fraunhofer IKTS
Fraunhofer Institut für Chemische Technologie (ICT)
Fraunhofer Institut für Solare Energiesysteme (ISE)
Freudenberg FCCT KG
FWB Kunststofftechnik GmbH
Gardner Denver Deutschland GmbH
Gebr. Becker GmbH
GHR Hochdruck-Reduziertechnik GmbH
Gräbener Maschinentechnik GmbH & Co. KG
Grundfos Management A/S
GSR Ventiltechnik GmbH & Co. KG
Heliocentris Energiesysteme GmbH
HNP Mikrosysteme GmbH
Hochschule für Angewandte Wissenschaften
h-tec Wasserstoff-Energie-Systeme GmbH
IRD A/S
IWAKI Europe GmbH
Karlsruher Institut für Technologie (KIT) Campus Süd Institut f. Werkstoffe der Elektrotechnik
Linde Material Handling GmbH
Magnum Fuel Cell AG
MTU Onsite Energy GmbH
Next Energy EWE-Forschungszentrum für Energietechnologie e.V.
Otto Egelhof GmbH & Co. KG Regelungstechnik
P21 GmbH
Plansee SE
PROTON MOTOR Fuel Cell GmbH
RBZ Riesaer Brennstoffzellentechnik GmbH
Rittal GmbH & Co. KG
Robert Bosch GmbH
ROFIN-SINAR Laser GmbH
Schunk Bahn- und Industrietechnik GmbH
Schwarzer Precision GmbH + Co. KG
SFC Energy AG
SGL TECHNOLOGIES GmbH
Siemens AG Energy Sector Fossil Power Generation
Siemens AG Industrie Sector Building Technologies Division GER I BT
SMA Solar Technology AG
Süd-Chemie AG
Truma Gerätetechnik GmbH & Co. KG
TRUMPF GmbH + Co. KG
TU Bergakademie Freiberg Inst. f. Wärmetechnik u. Thermodynamik Lehrst. f. Gas- und Wärmetechn. Anlagen

Umicore AG und Co. KG
Universität Duisburg-Essen Fakultät für Ingenieurwissenschaften Institut für Produkt Engineering
UST Umweltsensortechnik GmbH
Viessmann Werke GmbH & Co.KG
WILO SE
WITTENSTEIN cyber motor GmbH
WS Reformer GmbH
ZBT gGmbHZentrum für BrennstoffzellenTechnik
ZSW Zentrum für Sonnenenergie- u. Wasserstoff-Forschung Baden-Württ. GB Elektrochemische Energietechnologien

References

[1] Source: liG Research, 2007

[2] This ranking shows great differences in the number of patents filed. However, while this difference cannot be understated, the numbers need to be interpreted as the Patent Office in Germany has a narrower approach than those of the US and Japan regarding what can be patented.

[3] Source: MTU, WIPO Statistics database

[4] Source: VDMA Fuel Cells Survey 2009

[5] Source: Institut für Zukunftenergiesysteme (IZES)

Economic Risk and Potential of Climate Change

Prof. Dr. Peter Hoeppe, Head of Geo Risks Research/Corporate Climate Centre, Munich Re, Munich, Germany
Dr. Ernst Rauch, Head of Corporate Climate Centre, Munich Re, Munich, Germany

As extreme weather events affect the core business of insurance this industry has quite early analysed potential effects of global warming on natural catastrophe hazards. Munich Re already in 1973 has addressed this topic in a publication. Today climate change is regarded as one of the largest risks for insurance industry. Munich Re's experts have been researching loss events caused by natural hazards around the globe for over 35 years. These losses are documented in the NatCatSERVICE database currently documenting more than 27,000 single events.

In recent years we have seen many natural catastrophes with records in intensities and losses caused by them such as:

- The hundred-year flood in the Elbe region in Germany in the summer of 2002, still the most expensive natural catastrophe in Europe
- The 450-year event of the hot summer of 2003, which caused more than 70,000 heat fatalities in Europe
- The largest ever recorded number of tropical cyclones (28) and hurricanes (15) in a single North Atlantic season in 2005, with the strongest (Wilma – core pressure: 882 hPa), fourth strongest (Rita), and sixth strongest (Katrina) hurricanes on record.
- Hurricane Katrina, the costliest single event of all times, with economic losses of over US$ 125bn and insured losses of approximately US$ 60bn;
- In October 2005, Hurricane Vince formed close to Madeira, subsequently reaching the northernmost and easternmost point of any tropical cyclone.
- In 2006 record heat in July in the Netherlands: about 1000 heat fatalities.
- Winter storm Kyrill (January 2007) has caused the second largest losses in Europe caused by a winter storm
- Largest losses ever caused by flooding in the UK in June/July, 2007.
- Hurricane season 2008: Gustav had the highest ever measured gust wind velocity of a hurricane near the ground (340 km/h measured at a site in Cuba), Ike had the highest ever calculated destructive potential calculated by the Integrated Kinetic Energy Index.
- In 2009 tropical storm Grace set a new record as never before a tropical storm has been documented developing so far north-east in the Atlantic Ocean!

The analyses of the NatCatSERVICE data clearly show a dramatic increase in the number of natural catastrophes around the globe, with ever growing losses. The trend curve indicating the number of devastating natural catastrophes (losses > US$ 500m at current values or fatalities > 500) worldwide reveals an increase from about 17 per year at the beginning of the 1980s to about 33 at the present time and thus roughly a doubling (figure 1).

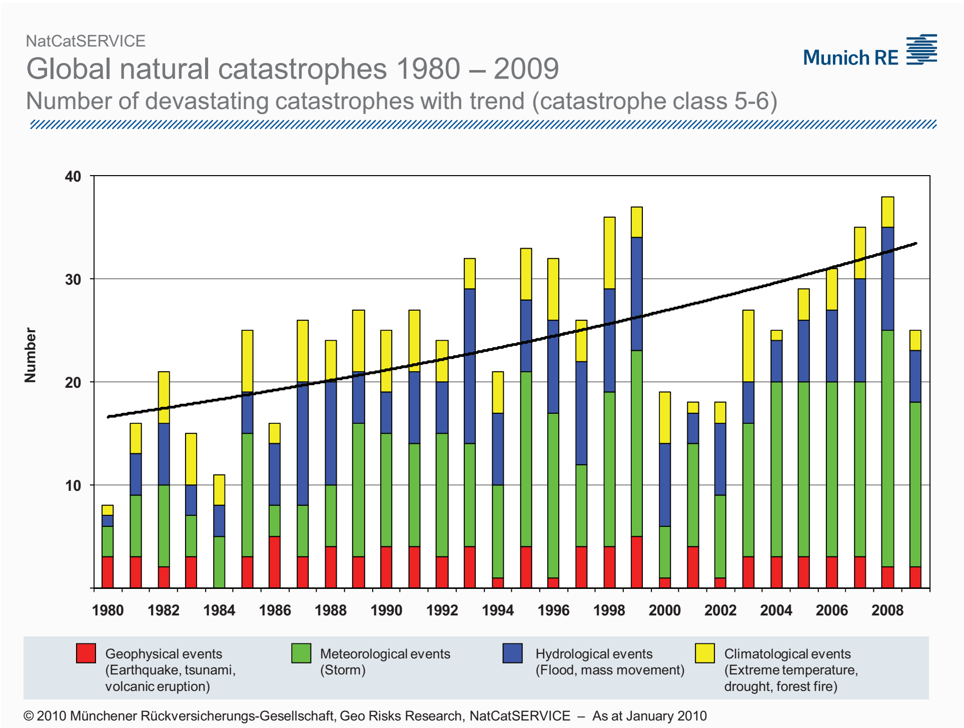

Figure 1: Annual number and trend line of devastating catastrophes (catastrophe classes 5-6) (Source: NatCatSERVICE, Munich Re).

Since 1980 on average 18% of the devastating weather events have occurred in Europe, the continent affected most has been Asia with 39%, second North America with 33%. In Europe 33% of the events have been caused by floods, 32% by wind storms, 25% by other weather related events and 10% by earthquakes.

Economic and insured losses resulting from weather disasters have risen even more sharply. In 2005, a record year, global economic losses were as high as nearly US$ 180bn and insured losses around US$ 90bn.

The main reasons for the sharp increase in losses from weather-related catastrophes are population growth, the settlement and industrialisation of regions with high exposure levels and the fact that modern technologies are more vulnerable to losses. The state of Florida in the USA, which has always had a high hurricane exposure, is a good illustration of the way that socioeconomic factors can act as natural catastrophe loss drivers. The population there has grown from three million in 1950 to the current 19 million.

As the rise in the number of natural catastrophes is largely attributable to weather-related events like windstorms and floods (figure 2), with no similarly strong increase in geophysical events such as earthquakes, tsunamis, and volcanic eruptions, there is some justification in assuming that anthropogenic changes in the atmosphere, and climate change in particular, play a decisive role. There has been more and more evidence to support this hypothesis in recent years. The fourth status report of the Intergovernmental Panel on Climate Change (IPCC 2007) regards the link between global warming and the greater frequency and intensity of extreme weather events as probable. The report finds, with more than 66% probability, e.g. that climate change already produces more heat waves, heavy precipitation, drought and intense tropical storms and that such effects will be growing in the future.

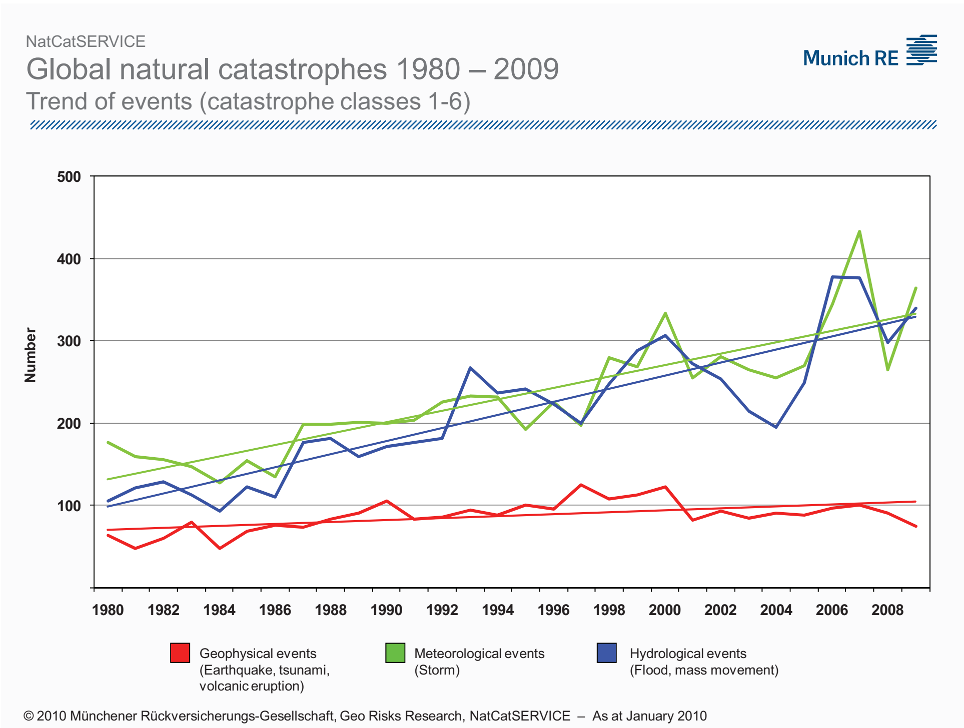

Figure 2: Annual numbers and trend lines of loss relevant natural events broken down to the different perils (Source: NatCatSERVICE, Munich Re).

The rise in global average temperatures significantly increases the probability of record temperatures. Higher temperatures also enable air to hold more water vapour, thus increasing the precipitation potential. Combined with more pronounced convection processes, in which warm air rises to form clouds, this results in more frequent and more extreme intense precipitation events. Already today such events are responsible for a large proportion of flood losses.

Now that a number of changes have already happened and some of the predictions for the coming decades have already been seen, the key issue is no longer if and when there will be conclusive proof of anthropogenic climate change. The crux of the matter is whether the existing climate data and climate models can provide sufficient pointers for us to estimate future changes with reasonable accuracy and formulate adaptation and prevention strategies in good time.

The insurance industry's natural catastrophe risk models have already been adjusted in the light of the latest findings. For instance, they now incorporate the increased hurricane hazard due to higher sea surface temperatures that will remain above the long-term average due to the ongoing cyclical warm phase in the North Atlantic and the continuous warming caused by anthropogenic climate change.

Global warming is one of the largest risks for humankind in this century. Mitigation of global warming is urgent in order to keep the changes manageable, ambitious reductions of CO_2, the most important greenhouse gas, are indispensable. In order to achieve a long term and sustainable solution the energy supply has to be transformed to carbon free renewable energies. In this context hydrogen will play an important role as an environmentally friendly energy carrier.

The insurance industry after having been one of the first alerters of potential climate change effects now consequently is providing solutions both for mitigation of and adaptation to the problem. Such solutions provide great business opportunities for the first movers in these new technologies. So e.g. Munich Re together with the Desertec Foundation has initiated the foundation of the Desertec Industrial Initiative GmbH, which is developing a business case for the carbon free generation of large amounts of electricity in the deserts of North Africa. By custom made insurance covers for innovative technologies like renewable energies and hydrogen technologies, incentives can be given for investments into such assets.

With our long experience we have not only created unique expertise on natural catastrophe risks in this changing world but also on insurance solutions for innovative climate protection technologies, hydrogen energy being one of them.

The Potential Role of Hydrogen and Fuel Cells

Prof. Dr. Detlef Stolten and Thomas Grube, Juelich Research Center, Institute for Energy and Climate Research, Fuel Cells (IEK-3)

Abstract

This paper outlines the role fuel cells and hydrogen can play in the future energy economy. The drivers to implement hydrogen are discussed with an emphasis on CO_2 emissions reduction. The different sectors in which hydrogen can contribute to clean solutions are mentioned. As for the transition to renewable energy, the stationary energy sector and transportation will grow together, even more through electro-mobility.

1 Introduction

There are three **drivers** for novel energy solutions which are internationally acknowledged: energy security, environmental protection and competitiveness. Their ranking differs by countries and shifts over time, but the general goals stay the same. Environmental protection splits into the global issue of climate change and local pollution. Local pollution is particularly important in modern urban sprawls and hence fuel cell development for automotive applications was triggered in California owing to the high level of local pollution in the Los Angeles basin in the late 1980s. As the issue of global climate change became increasingly recognized, fuel cell technology was geared toward less CO_2 emissions in the energy pathway contributing to the general **goals** for energy technology. Energy diversity which goes along with the introduction of renewable primary energy sources helps achieving energy security. In other words, if the issue of environmental protection is pursued effectively energy security is a natural outcome. **Tools** procuring these goals are high conversion efficiencies in the energy pathway, enhanced use of renewable primary energy, the introduction of storage capability to the energy pathway for enhanced use of intermitting renewable primary energy, a further focus on a low level of limited emissions and reduction of overall CO_2 emissions. This translates into four **grand challenges** of energy technology: renewable energy, electro-mobility, efficient central power plants and cogeneration.

2 Anthropogenic climate change is real

Even though minor irregularities have recently been discovered in the 4^{th} Assessment Report of the Intergovernmental Panel on Climate Change [1], there is no reason to doubt the vectors outlined in the report. Additionally, the limelight of the media has recently shifted away from climate change to the more palpable issues arising from the financial and economic crisis.

In the longer term though, climate change can be expected to alter the living conditions to the worse. The following picture underlines that the trend of rising temperatures coincides for the measured data (black lines) and the modeling data when anthropogenic impact on climate change is considered. The rising temperature trend fits the measured data only when anthropogenic CO_2 emissions are included, cf. Figure 1.

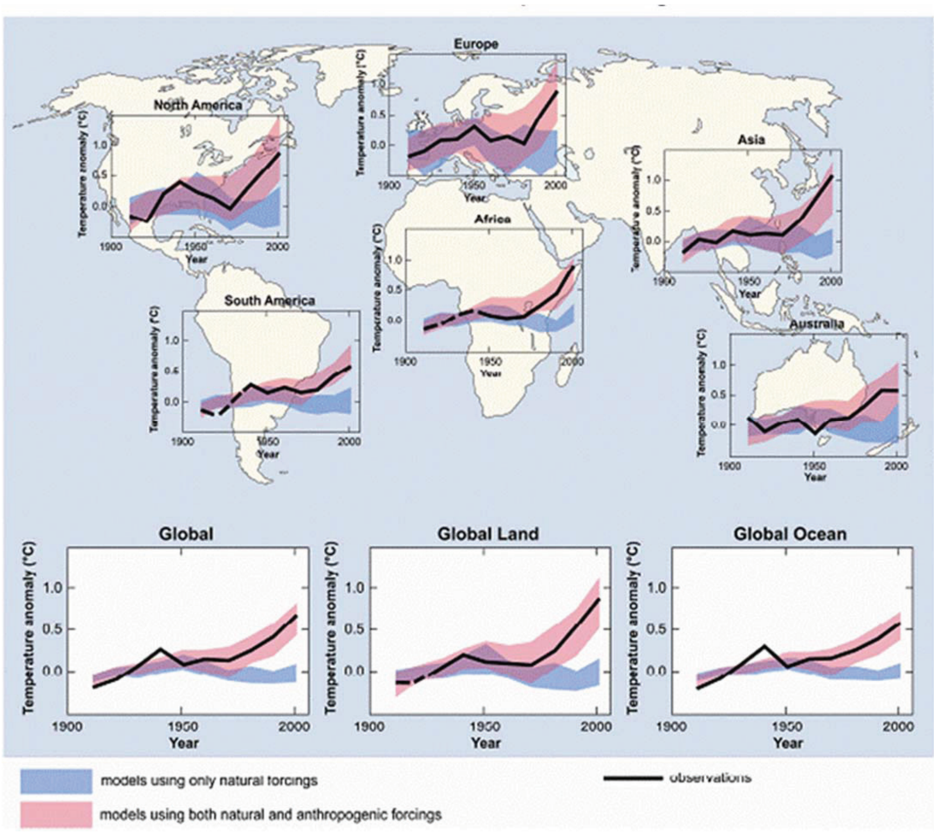

Figure 1: Modeled temperature data with (purple) and without (blue) anthropogenic impact in comparison to the measured Data (black lines). The modeling data bands are composed of the results of different models and hence exhibit a certain bandwidth. The modeled data fit to the measuring results only when anthropogenic effects are considered [1, Fig 2.5 p 40].

Over the past 20,000 years climate gases increased notably when the ice age ended about 12,000 years ago. The increase then leveled off until the industrial revolution happened. From that time on the climate gas concentrations shot up to all-time highs far beyond the levels over the past 650,000 years owing to anthropogenic emissions. Consequently, the radiative forcing of the atmosphere (the property of the atmosphere to absorb incoming solar radiation) leaped up. Figure 2d exhibits the change of the radiative forcing over time. Now, the challenge for mankind lies in adapting to the inevitable climate change which is going on rapidly and to mitigate potential further effects by cutting the climate gases down to levels which allow for a limited increase in the average global temperature. In mitigation novel energy technologies come in and hydrogen and fuel cells will play a role.

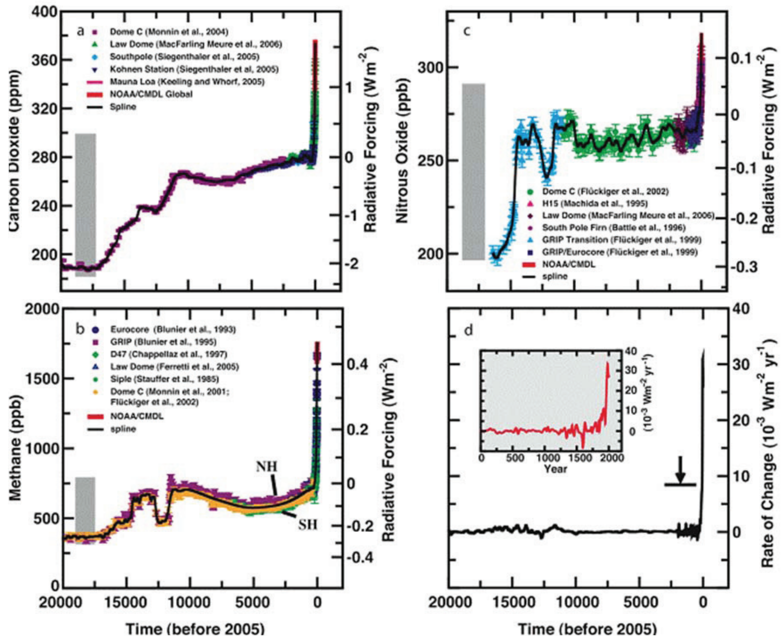

Figure 2: Concentration and radiative forcing of climate gases over the past 20,000 years. The grey bars show the band in which the climate gases naturally varied over the last 650,000 years. Whereas the natural variation over the past 20,000 years occurred within these bands, today's levels exceed the peaks concentration of the natural variation significantly [2].

Since these changes have implications on the food chain and food supply as well as water supply and land distribution, the IPCC concludes in its Summary of the 4th Assessment Report that 'the existing population can only be supported by extensive use of technology, in OECD countries as well as in developing countries' and that 'further expansion can only be managed by further advancement and deployment of technology'.

3 Options to Reduce the CO_2-Emissions and the Role of Hydrogen

Socolow introduced the idea of stabilization wedges, with which he associates the different contributions available technologies can make to the total need of reduction in CO_2 output [3]. With this approach he suits the need for imminent action on climate change.

Figure 3 shows the Stabilization Triangle, the absolute emission of CO_2 that is to be compensated by applying CO_2 friendly technologies within the next 50 years; based on 2004 as a starting date. He argues that existing technologies and technologies that can be implemented in the foreseeable future should be used to confront climate change for two reasons: on the one hand side this is possible and on the second hand side later action would require much stricter action since more CO_2 already accumulated. This triangle can be broken down to contributions of different sectors, as visualized in Figure 3.

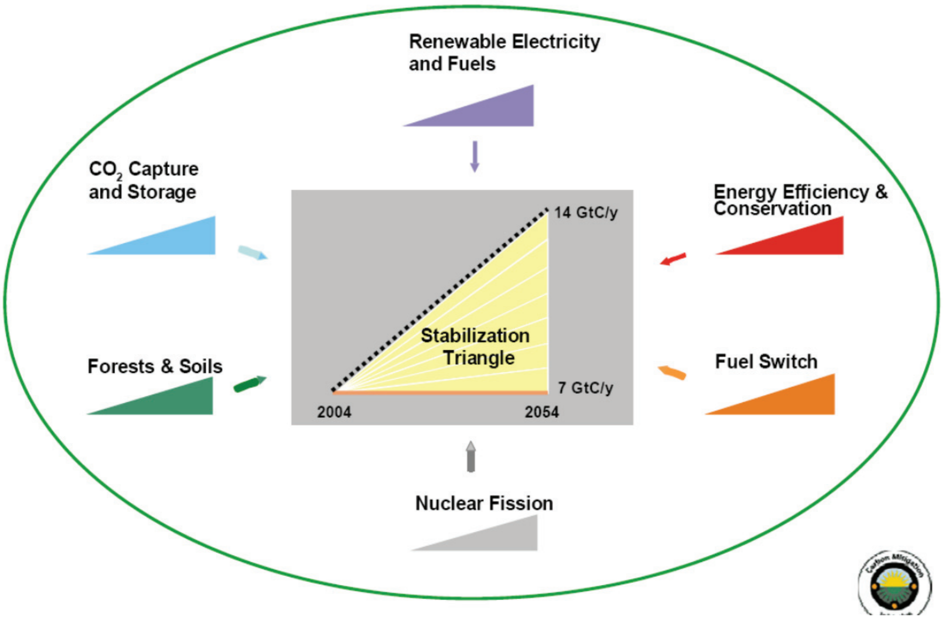

Figure 3: Listing of the different sectors that can contribute to the Stabilization Triangle.

Hydrogen technology comes in in four out of six of the sectors depicted in Figure 3. Via **electrolysis** of **renewable energy** and hydrogen storage, hydrogen technology bears a great potential to compensate for the fluctuation of renewable energy. If mass storage is required it can be stored in geologic saline formations. Compressed air storage delivers a physical storage density of 10 MJ/m^3 at 100 bars. Hydrogen on the contrary delivers a chemical storage density of 1014 MJ/m^3 at the same pressure, real gas properties considered. The physical compression energy is just about 1% and needs not be considered. **Fuel cells** contribute to **energy efficiency and conservation**. For **passenger cars and urban buses** hydrogen is a clean fuel for fuel cells with a reasonable storage density that can substitute gasoline and diesel in mass markets, providing a **fuel switch.** Finally in **CO_2 capture and storage**, hydrogen also plays a role when **pre-combustion capture** in IGCC power plants is applied. In summary, hydrogen plays a crucial role in four out of the six important contributing sectors to cut down CO_2 emissions.

4 Reflection on the Importance of Energy Density of Renewables

As of 2010 the catch words of the energy and climate program in Germany [4] are: cogeneration, renewable resources, CCS technology, biogas, biofuels and electro-mobility.

Renewable energy provides a great potential as it is abundant. As for solar energy, the solar influx on 1% of the usable land mass is sufficient to meet the complete world energy demand with electric power; conversion efficiency included. The challenge with renewable energies lies in harnessing them though, because of their low energy density and their strong fluctuation. The following picture shows the fluctuation of the wind power influx into the TenneT Grid in Germany as of May 2010 [5].

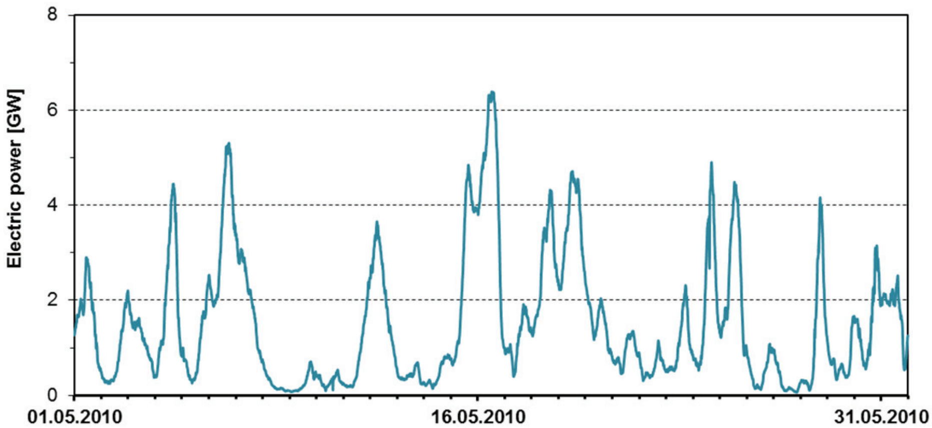

Figure 4: Fluctuation of the power influx in the TenneT balancing group based on quarterly hourly values in May 2010 [5].

Figure 4 shows that with wind energy there is basically no base load that can be provided; the influx changes between zero and hundred percent. Hence, the first and foremost requirement for a transition to renewable energy is energy efficient and cost-effective storage and reconversion to electric power. Table 1 shows the energy density of different renewable energies and puts them into a perspective by comparing them to oil extraction.

The comparison shows, that hydropower is **most efficient to harness**, all renewable energies considered. The second most effective renewable energy is wind power, which is already one order of magnitude lower than hydropower, but one order of magnitude higher than photovoltaic power. The weakest case is represented by biomass, which is three orders of magnitude worse than hydropower. The advantage of biomass is that no major installation is needed if it is grown on farmland. Yet, the energy input into fertilizers and tilling as well as collecting the biomass is to be considered. These factors make the efficiency of biomass very depending on the specific situation under which it is grown, resulting in a broad band from high efficiencies down to questionable efficiencies.

The comparison shows that oil – and the same holds true for coal – is the most convenient energy to harness because of its high energy density that was created over millions of years in geologic processes out of biomass. As for renewable energies there is a clear ranking from hydropower over wind power to photovoltaic power and biomass. Beyond the high energy density of hydropower, a major advantage is the base load capacity of run-off-river power plants. Once the river run-off is quantitatively used – as it is the case in many countries with high population densities – artificial lakes are needed for further development of water resources. The second best solution in terms of energy density, which also does not consume the land which it is put on, is wind power. Only the third best to harness is solar energy. From a primary energy point of view – except for geothermal energy – all other renewable energy is based on the solar influx to the earth, be it directly through radiation on PV and crops or indirectly through cloud formation fueling hydropower. Therefore, their potential is inherently than that of solar energy. Often the potential was considered the primary argument for choosing the primary energy. This paper argues that the energy density is more important since it determines the effort and cost to harnessing the renewable energy.

Table 1: Listing of power densities of renewable energy in comparison to fossil oil based on averaged annual values to account for the fluctuations. As active area for hydropower the area of the water dam was used, for wind power the footprint that moving rotor blades cover was used, for photovoltaics the cell area was used and for biomass the tilled land was used. These values are compared with the power density of an oilfield, which can provide this power density just for limited time until it is exhausted. This comparison is fair, since the installation for harnessing the renewable energy has a lifetime in the same range of 10 to 20 years.

Hydropower	2 – 4	$kW\ m^{-2}$	
Wind power	120 – 140	$W\ m^{-2}$	
Geothermal	0.6 – 35	$W\ m^{-2}$	
Photovoltaic	15	$W\ m^{-2}$	
Biomass, 1st Generation	0.1	$W\ m^{-2}$	
Biomass, 2nd Generation	< 8	$W\ m^{-2}$	
Biomass, theoretical	1 – 2	$W\ m^{-2}$	Crop, EU
	5	$W\ m^{-2}$	Crop, equatorial
	40	$W\ m^{-2}$	Bacteria, EU
	75	$W\ m^{-2}$	Bacteria, equatorial
Oilfield	200 – 300	$kW\ m^{-2}$	Best case, 20 years
	100	$kW\ m^{-2}$	Average, 10 years

Since in Germany hydropower is at its capacity limit, wind power plus electrolysis for hydrogen storage represents an outstanding opportunity, which can be complemented by solar power. If the ponderous fluctuations shall be compensated without causing further CO_2 emissions, water electrolysis with hydrogen storage becomes indispensable.

5 How Hydrogen Fits into the Existing Energy Structures

The primary use of hydrogen ought to be in **fuel cell vehicles** for sake of efficiency and higher revenues for transportation fuels than for heating fuels. First of all, hydrogen vehicles are already at a highly developed level, delivering driving properties like existing vehicles with internal combustion engines, except for price and longevity which are subject to further development until the envisaged market introduction in 2015. Hydrogen fits well into the **semi-centralized** distribution of existing liquid fuels at gas stations. It poses new challenges to the distribution from its source to the gas stations. For the time being, the following options exist: hydrogen supply via pipelines, on-site natural gas reforming, on-site water electrolysis and – for the market introduction phase – supply of liquid hydrogen.

6 Cost of Hydrogen Gas Stations vs. Electric Charging for Battery Vehicles

The advantage of this semi-centralized approach becomes palpable when it is compared to the necessary amount and cost of electrical charging stations for batteries, representing the completely decentralized approach. Assuming an average gas station supplies in between of 1,500 and 2,000 kg hydrogen per day and 4 to 5 kg per car are fueled, 300 to 500 cars per day would be served. With an average cruising range of 12,000 km per annum and 500 km cruising range per tank load, the average car needs to be fueled every 15 days. Hence, one gas station would serve about 4,600 to 7,700 cars according to these assumptions. With 41.7 million vehicles on the road tin Germany in 2010 [6] according to the assumptions above 5,500 to 9,000 gas stations selling hydrogen would be needed. 9,000 gas stations might also be enough for a full spatial coverage of supply, as the comparison to the existing number of 14,700 gas stations in 2010 shows [7]. Since this number shrinks continually by about 160 gas stations per annum [7], an oversupply with the existing structure can be assumed.

For electric vehicles it can be assumed that at least 1.5 charging stations per car will be needed, since the charging process is time-consuming and the cars need to be fully charged when start cruising because of the short cruising range. Hence, one gas station compares to about 7,000 to 11,500 electric charging stations. At average investment cost of €2,000 per electric charging station [8] the total amounts to €14 - 23 million compared to about €2 million per hydrogen gas station [9]. It can be concluded, that charging station infrastructure for battery vehicles is an order of magnitude more expensive than the semi-centralized gas station infrastructure for fuel cells; full coverage of the market for each technology presumed. Admittedly, further infrastructure cost like hydrogen pipelines or electric grid reinforcement or extension is not considered since it is subject to further investigation. This estimation supports the idea that the semi-centralized supply of fuel is much more efficient than the fully decentralized approach of electrical battery charging; inconvenience of charging times and small cruising range not considered.

7 Transportation of Energy via Hydrogen and Electricity

The transportation of energy via gases is generally very effective. The energy loss in hydrogen pipelines is about 3% per 1,000 km. A conventional 400 kV AC power line entails about 9% of loss per 1,000 km [10]. High voltage DC-DC power lines lose only 2 to 3% energy per 1,000 km, but have an offset of 2 to 3% transformation losses at either end of the line, that sum up to 4 to 6% in total. Hence, it is more effective to transport gases like hydrogen over long distances. For short distance transportation and imminent use electricity is most efficient and cost effective. Other than electricity hydrogen can effectively be stored, like in great quantities in salt caverns comparable to natural gas. This makes hydrogen an effective management tool not just for short-termed fluctuations, but particularly for seasonal shifts of renewable energy input.

8 Energy Storage Density of Fuels and Batteries

Table 2 shows the comparison of hydrogen with gasoline, ethanol and batteries in terms of the energy storage density. The energy density of the chemical bond between two carbon atoms is very high, delivering a high energy density of fossil fuels and ethanol. This convenient situation will not be reached again with any environmentally friendly – i.e. CO_2 free – energy carrier. Hydrogen offers a realistic compromise which allows for a cruising range in vehicles of 400 to 700 km, depending on the storage design. The high efficiency of the fuel cell on board the vehicle, which is about twice as high as that of a gasoline engine, in respective driving cycles compensates for the lower energy density. The efficiency of the fuel cell is particularly high because vehicles are mostly operated in part load. Whereas internal combustion engines decrease in efficiency in part load, the fuel cell systems stay stable or even slightly increases in efficiency, due to their electrochemical nature.

Via **water electrolysis** hydrogen can be generated in the most efficient and cleanest way, reaching 80% of efficiency based on the lower heating value. The longevity and performance under dynamic load from renewable energy is subject to future investigation.

Table 2: Energy density of gasoline and ethanol in comparison to hydrogen and to batteries

	Physical capacity		Technical capacity	
	$[MJ\ l^{-1}]$	$[MJ\ kg^{-1}]$	$[MJ\ l^{-1}]$	$[MJ\ kg^{-1}]$
Gasoline	31	43	–	35
Ethanol	21	27	–	
Hydrogen	5 @ 700 bar	120	4 @ 700 bar	15
Batteries	1.5	0.5	Cooling cells	ditto

Hydrogen fuel cells can be applied for long-distance driving and city operation in vehicles and light duty trucks. They are to compete in the future with battery cars for short distance commuting, cheaper gasoline or diesel hybrid cars that cannot provide the effectiveness in CO_2 reduction as electro-mobility options do. Heavy duty trucks though are very likely to be operated with liquid fuels even in the long-term. Owing to the high energy consumption of the engines there is no concept of using hydrogen as a fuel for its remarkably lower energy density. In heavy-duty trucks, aviation and rail applications as well as marine applications biofuels are likely to provide the best clean alternative. Beyond saving on CO_2, electro-mobility for vehicles and urban buses in general – i.e. batteries and hydrogen operated fuel cells – saves on nitrogen oxide emissions that are produced in the combustion process as well as on particulate emissions as soot from the combustion process and as abrasive wear from breaking which is partially done through regenerative braking. Table 3 lists the characteristics of a cutting edge fuel cell vehicle.

Table 3: Characteristics of the Mercedes-Benz B-Class F-CELL [11]

Drive train	Electric motor with fuel cells
Net power $[kW]/[PS]$	100/136
Nominal torque $[Nm]$	290
Top speed $[km\ h^{-1}]$	170
Fuel consumption NEDC $[l_{Diesel\ equivalent}\ (100\ km)^{-1}]$	3.3
CO_2 total min.–max. $[g\ km^{-1}]$	0.0
Cruising range NEDC $[km]$	385
Capacity/ power lithium ion battery $[kWh]/[kW]$	1.4/35
Freeze start-up capability	Down to -25°C

These characteristics show that fuel cell vehicles fueled with hydrogen are full substitutes for existing gasoline or diesel vehicles. Their cruising range is less than that of existing cars, but they can be refueled swiftly.

9 A Glance on Stationary Applications

For stationary applications natural gas is considered as being CO_2-lean and cheap. Natural gas burns with little emissions and can be used in fuel cells via reforming. Hence, there are no activities to introduce hydrogen as a staple energy for stationary applications. Fuel cell types for stationary applications are the phosphoric acid fuel cell, molten carbonate fuel cell, the solid oxide fuel cell and the high temperature polymer fuel cell, mentioned in the ranking of their development stage. Hydrogen as well as biogas may be well used in the future.

10 Summary

Anthropogenic climate change can be identified as the foremost driver for changes in the energy sector in Germany and many other countries. Renewable primary energy such as wind or solar energy introduces strong fluctuations to the electrical grid. Hydrogen is well suited to compensate these. In a worldwide consensus fuel cell vehicles are designed today for hydrogen as a fuel. These cars are full substitutes of today's vehicles, other than battery cars that impose strong limitations on their users. Since they run on hydrogen, the electric power sector and the fuel supply for vehicles will be closely connected in the future through electrolysis, when fuel cell cars will be introduced.

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NIP – The German National Innovation Programme Hydrogen and Fuel Cell Technology

Dr. Klaus Bonhoff, NOW GmbH Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie, Berlin, Germany

Summary

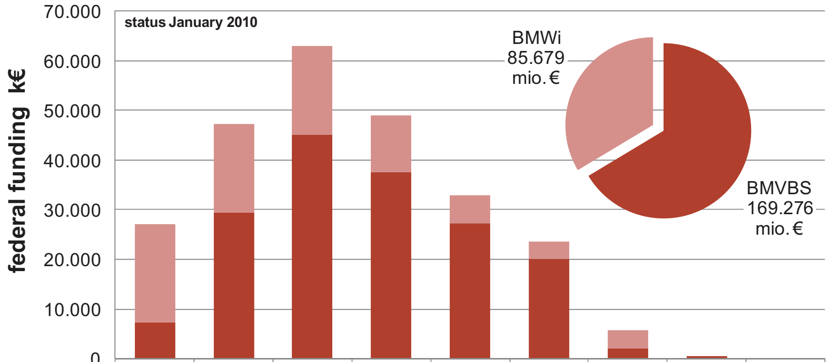
Mobility and energy supply are essential elements of modern societies. Participation in social and cultural life, commuting to work, the transportation of goods, and provision of power and heat for houses – all this will only be possible in the future with modern emission-free and efficient technologies. Similarly, economies will only be globally competitive through market leadership in these areas. Hydrogen and fuel cells play a key role in the mobility and energy supply of tomorrow.

The NIP – the National Innovation Programme for Hydrogen and Fuel Cell Technology – was launched in 2007 to accelerate market preparation for these technologies in Germany. Since then, projects with federal funding of almost €255 million for R&D as well as demonstration activities have been started, showing that industry is committed to developing future-oriented products deploying hydrogen and fuel cell technologies.

Looking at application areas, automotive manufacturers are preparing for market entry of series production passenger cars starting around 2015. This does not begin with hundreds of thousands of cars per year, but with a gradual ramp-up. Hydrogen infrastructure must be simultaneously established nationwide with special attention to carbon dioxide-free production pathways. In the stationary application area, industrial combined heat and power systems and residential power supply systems are expected to complete their market preparation phase within the next five years, in order to then be introduced as commercial products to the market. Special markets such as back-up power systems or specialty vehicles are also assuming an important role. They represent early market opportunities as well as pioneering sales potential for suppliers.

1 Introduction

Hydrogen and fuel cell technologies will play an essential role in the future of mobility and energy supply. In 2006, government, industry and science initiated the German National Innovation Programme Hydrogen and Fuel Cell Technology (NIP) as a strategic alliance. The NIP is intended to speed up the process of market preparation for products based on these future-oriented technologies. The total budget of the NIP to fund individual projects over a period of ten years (2007-2016) amounts to €1.4 billion. The Federal Ministry of Transport, Building and Urban Development (BMVBS) has dedicated €500 million for demonstration activities and the Federal Ministry of Economy and Technology (BMWi) will provide at least €20 million over the ten-year period. In total, this represents half of the overall budget, with the other half contributed by participating industry. Figure 1 shows the annual federal funding in Germany since 2008 for those projects within the NIP that were approved by January 2010, adding up to almost €255 million (BMVBS: €169,276 million; BMWi: €85,679 million).



	2008	2009	2010	2011	2012	2013	2014	2015	2016
BMWi	19.713	17.842	17.842	11.515	5.674	3.495	3.564	0	0
BMVBS	7.280	29.317	45.029	37.498	27.309	20.092	2.151	600	0

Figure 1: Approved NIP-projects (demonstration (BMVBS) and R&D (BMWi)).

The large-scale demonstration projects within the NIP are grouped into comprehensive lighthouse projects and take place under real-life conditions. Project partners thus work together efficiently on issues and challenges which they otherwise would have to face alone and with considerably higher individual effort.

The NIP is divided into three programme areas in order to advance numerous hydrogen and fuel cell technology product and application options in equal measure, and to address the application-specific challenges of market preparation in a targeted way. The particular programme areas are: »Transport and Hydrogen Infrastructure«, »Stationary Energy Supply«, and »Special Markets«. With an eye to series production of components, an explicit focus in all programme areas is also on strengthening the supply industry.

2 Transport and Hydrogen Infrastructure

The challenges for transportation are constantly increasing with regard to:

- Security of supply (decreasing oil dependency through diversification of the fuel portfolio, use of domestic energy carriers like synthetic fuels, electricity, and hydrogen)
- Environmental sustainability of supply (climate and environmental protection through increasing usage of renewable energies and more efficient drive train technologies)
- Affordability of supply (through decreased fuel consumption, cost effective fuels and moderate costs for purchase)

Incumbent technologies currently in the markets will be further optimised, but these improvements are insufficient to reach global climate targets. For example, in the European transport sector, an 80% reduction in greenhouse gas emissions by 2050, which is necessary to remain within the 2 degree target, requires maximum permissible emissions in new vehicles (passenger cars and light duty vehicles) of approximately 80g CO_2 per km by the year 2020. By 2030, this figure must be reduced even further to less than 60g CO_2 per km [1]. The optimisation of today's fuels and power drive technologies needed to meet these goals will in all probability not be achievable. It is therefore crucial that renewable energy sources and more efficient drive train technologies are implemented to enable the transport sector to meet its environmental targets. The development and embedding of new technologies for improved efficiency and sustainability will bring about a paradigm shift away from oil to a range of solutions taking regional considerations into account. An area offering vast potential in this context is hydrogen with fuel cell technology.

Leading OEMs like Daimler, Ford, GM/Opel, Honda, Hyundai, Kia Motors, Nissan/Renault and Toyota publicly announced in September 2009 that they strongly anticipate that a significant number of fuel cell vehicles could be commercialized from 2015 onwards. This number is expected to be as high as a few hundred thousand units over the life cycle on a worldwide basis. The announcement identified Germany as the lead market in Europe, where hydrogen vehicles are to hit the road first, and where the built-up of substantial numbers of filling stations is to commence.

The parallel step comprises the further development and tailored build up of the hydrogen fuelling infrastructure. These activities are promoted by *H2 Mobility*, a public private partnership that focuses specifically on developing the business case for an area wide hydrogen infrastructure in Germany during Phase I, which will run until 2011. *H2 Mobility* was launched in September 2009 with the signing of a “Memorandum of Understanding” between Daimler, EnBW, Linde, OMV, Shell, Total, Vattenfall and NOW. Since then, Air Liquide and Air Products have also joined the initiative. Taking Germany as a lead market and starting point will also help with infrastructure development in the whole of Europe.

To support and to accelerate the market preparation of technologies in the field of road transportation, the NIP focuses on deploying and demonstrating hydrogen vehicles and the associated infrastructure within its lighthouse project *Clean Energy Partnership (CEP)*.

2.1 Clean Energy Partnership (CEP)

The *CEP* was launched in 2002 as an international corporate partnership. Its aim is to demonstrate the every-day suitability of hydrogen as a fuel for vehicles and to test the infrastructure for refuelling such vehicles. In September 2008, the *CEP* embarked on its second phase. Since then, 48% of *CEP* funding contributions comes from the NIP. Currently, the *CEP* concentrates on the key regions of Berlin and Hamburg, with North Rhine-Westphalia added as a CEP-region in May 2010. CEP is the largest undertaking of its kind in Europe. More than 30 passenger cars are in daily use, and the expansion of this fleet continues. Furthermore, Berlin and Hamburg continue to boast operating fleets of public buses. As these fleets grow, the associated hydrogen infrastructure will mature accordingly. The CEP partners - vehicle manufacturers (BMW, Daimler, Ford, GM/Opel, Toyota and

Volkswagen), oil companies (Shell and Total), energy providers (Vattenfall), the gas industry (Linde) and public transport providers (BVG and Hochbahn) cluster their activities in the super ordinate modules to ensure a unified CEP voice. These common tasks include: coordination and management, project representation, knowledge and information management and public relations.

Opening the new hydrogen fuelling station in Berlin's Holzmarktstrasse in May 2010 marked an important milestone for the *CEP* on its way to expanding the infrastructure for hydrogen refuelling. At this station, project partners TOTAL, Linde and Statoil deployed innovative technologies to compress and store the gaseous hydrogen to up to 1,000 bars. The planned station at Sachsendamm in Berlin from Shell addresses large-scale validation of a scalable hydrogen fuelling station concept on the basis of liquid hydrogen transfers and a 900 bar cryopump. Subterranean installation of plant technology in order to reduce its footprint will also be demonstrated. Also in Hamburg a new hydrogen fuelling station is to be constructed by Vattenfall and Shell. The fuelling station in the HafenCity will serve to supply public city buses and private vehicles. Besides gathering practical experience in handling hydrogen safely, a further focus lies in energy balance optimisation. Incorporation of an innovative compressor and electrolyser aims to accomplish this goal. The use of power from regenerative sources of energy is the guarantee for a sustainable form of individual mobility. Operating experiences with regard to the hydrogen infrastructure for cars and busses will be gathered throughout these projects as a basis for the establishment of a future hydrogen station network.

In addition to the demonstration activities within the CEP, supporting R&D covers the optimisation of specific fuel cell components like a mass-producible gas diffusion layer, an electric turbo charger for the air supply or next generation passenger car and bus fuel cell system development and validation.

2.2 Hydrogen production

Next to electricity, hydrogen is considered to be the energy carrier of the future. It can be made from various energy sources, can be easily stored, is highly efficient in the operation of fuel cells and produces virtually no emissions. Its use opens up new perspectives for energy supply especially when it comes to transportation fuels.

Studies have shown that large scale hydrogen production via wind power, biomass and coal (with CCS in the longer term) as well as via natural gas and from industrial by-products (in the initial phase) are feasible from a technical and economic point of view. The same applies for the necessary infrastructure, distribution and storage technology so that the complete hydrogen value chain is ready for implementation in the coming years.

According to the study GermanHy [2] hydrogen could, depending on the scenario, cover between 23% and 40% of the energy requirements in the transport sector in 2050 and thereby supply up to 70% of passenger cars and light commercial vehicles. To generate hydrogen, a mixture of different primary energies will be used, amongst which wind energy is likely to be the most significant long-term option in Germany. From a cost perspective following the launch phase, hydrogen costs range between 3 and 4 €ct/km. Carbon dioxide emissions from transport will drop by up to 80% in the longer term, and the share of renewable energies in the production of hydrogen could increase by over 60% by 2050.

Within the NIP, specific demonstration projects address the production of hydrogen based on renewable primary energy sources. This includes innovative gasification processes using biomass as well as electrolyser-based systems powered by wind energy. Besides technical aspects, questions regarding the integration of such devices in the overall energy market considering fluctuating energy supply from renewable power sources are being addressed.

If hydrogen technology represents a large share in Germany's future transportation systems, it will significantly contribute to Germany's future security of energy supply, and the fulfilment of EU climate change targets. Moreover hydrogen paves the way for new possibilities in the area of cutting edge technology, innovation, and as a result, global competitiveness.

The existing barriers to the market introduction of hydrogen as a fuel and respective vehicles are threefold. Firstly, the cost of the technology needs to be reduced over the entire value chain, but primarily in the vehicle and the hydrogen distribution and refuelling infrastructure. Secondly, hydrogen production needs to reduce its CO_2 footprint and thirdly, investment schemes for setting up the hydrogen refuelling infrastructure need to be identified.

The NIP addresses cost reduction of fuel cells as well as hydrogen production and refueling technologies in various projects. One example with regard to automotive fuel cell system cost shows that reductions of more than 90% were achieved from one generation to the next through integration of components, optimized manufacturing processes, use of new materials and technologies, and economies of scale (figure 2).

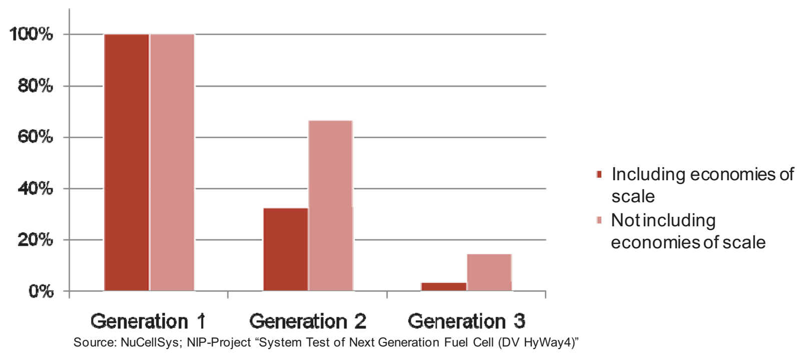


Figure 2: Cost reduction of fuel cell system (not including the stack).

3 Stationary Energy Supply

Stationary fuel cell systems provide power, heat and refrigeration in residential buildings and on ships, as well as for commerce and industry. They are expected to be ready for widespread use before the decade is out after a further testing phase. New, highly efficient technologies make a significant contribution to climate protection. Around two thirds of the overall energy demand is associated with electrical power, heating, cooling and hot water. Due to their high electrical efficiency as well as their co-generation capability (combined heat and power systems) fuel cells significantly reduce energy consumption and related emissions. Using biogenic fuels such as biogas, a virtually CO_2-free energy supply is possible.

Highly efficient high temperature fuel cell systems powered by gas from sewage plants and biogas facilities are the focus of the NIP lighthouse project *NEEDS* (New Ecologic Energy Decentrally Supplied). Demonstrating the production of CO_2-neutral power, heat and refrigeration fuel cell power stations will supply energy to hospitals, factories, office buildings and indoor pools.

Within the framework of NIP, other lighthouse projects in stationary power supply are *Callux* and *e4ships*.

3.1 Callux – fuel cells in residential co-generation systems

Fuel cell heating systems convert hydrogen to power and heat via an electrochemical process. This makes them ideal for environmentally friendly implementation in buildings. In contrast to conventional systems where mechanical energy is converted to electricity, these innovative small combined heat and power systems are highly efficient. They boast vast effectiveness and guarantee low emissions thanks to their direct conversion of energy. A reformer produces hydrogen from natural gas directly on site. And thanks to the existing infrastructure, this is easily available — even as biogas.

The lighthouse project *Callux* intends to test fuel cell-based combined heat and power systems in residential applications so that they can be deployed for mass use within the coming decade. The Latin terms »calor« and »lux« mean »warmth« and »light«. Together they form the expressive name »Cal-lux« chosen for this comprehensive lighthouse project within the NIP. With the purchase, installation and operation of up to 800 fuel cell heating systems, the initiative represents Germany's largest field trial for fuel cells in homes. The goal of *Callux* is to pave the way for the market introduction of natural gas-powered fuel cell heating systems, enabling such systems to be reliably implemented in the future for daily use. The project began in September 2008 and is scheduled to run for seven years. The demonstration activities within *Callux* are supported by focused R&D addressing performance enhancement as well as cost reductions.

Callux partners are the energy firms EnBW, E.ON Ruhrgas, EWE, MVV Energie and VNG Verbundnetz Gas, the system manufacturers Baxi Innotech, Hexis and Vaillant, and the Centre for Solar Energy and Hydrogen Research — ZSW (Zentrum für Sonnenenergie- und Wasserstoff-Forschung). ZSW coordinates the cooperation between partners on the project level. Besides evaluating specific projects in this context, NOW handles the aligned knowledge management and paves the way for international cooperation.

The energy supply firms negotiate long-term contracts with equipment manufacturers independently of one another to examine and test the technology in practice. They procure cutting-edge fuel cell heating equipment, which they put at the disposal of interested households. To be in a position to obtain verifiable, scientific results, the same targets and guidelines apply to all involved. In May 2010, fifty systems — regionally bundled — were installed across 13 German states. This number is set to increase to around 800 within the next several years.

The fuel cell equipment is especially designed for the basic needs of detached and semi-detached houses. Their thermal performance is rated at 2kW and electrical at approximately 1kW. Regarding the fuel cell technology itself, depending on the manufacturer either low-temperature PEM, high-temperature PEM or SOFC systems are being deployed. A natural gas burner ensures coverage during peak demand periods, if required. Meanwhile, a central control unit manages the entire system. In contrast to electricity production in central (off-site) power plants and separate heating in a boiler or furnace, up to 30% of primary energy can be saved.

Besides addressing technical issues, the *Callux* partners endeavour to minimise potential barriers to market entry. To achieve this goal, diverse and in part interdisciplinary issues are being addressed. Market partners and tradesmen in the sanitary-heating-climate field must, for example, be trained in time and be prepared for their future work on the new equipment through continuing, practical education measures. Joint communications activities by the consortium will ensure the public is informed about the new technologies and that interest among potential customers is fostered. Simultaneously, market and customer requirements must be clearly defined. For this purpose, the parties will conduct extensive market research. Interfaces must be also be standardised to enable communication between the fuel cell heating equipment and household energy management systems.

Through binding orders of larger quantities, along with sophisticated concepts for supply structures, delivery chains will be established and finally costs reduced. All *Callux* activities are designed to promote and introduce the new technologies of fuel cell heating equipment as an efficient, climate friendly and cost saving form of energy supply for buildings, promoting added value in Germany.

3.2 e4ships – fuel cells in maritime applications

Whether a cruise ship, research craft, merchant vessel, ferry or yacht: in the future, highly-efficient, quiet and low emission power and heating will be brought on board through fuel cells. Initiated in July 2009 and operating until 2016, *e4ships* is the lighthouse project within the NIP in which well-known German dockyards and shipping lines, leading fuel cell manufacturers and classification societies will be testing the functionality of fuel cells as an onboard supply of energy under rugged maritime conditions. Current partners are: AIDA Cruises, CMT, DNV, Flensburger Schiffbau- Gesellschaft, Lürssen, Germanischer Lloyd GL, hySOLUTIONS, HAW Hamburg, Helmut-Schmidt-Universität, Imtech, INVEN Engineering, MEYER WERFT, MTU Onsite Energy, Öl-Wärme-Institut (ÖWI), Reederei Rörd Braren, Proton Motor, ThyssenKrupp MS, VSM and ZBT.

e4ships is divided into several projects to demonstrate innovative technologies. A high-temperature fuel cell is to be tested on board a cruise ship as a modular energy supply system that is run by natural gas. Following testing, the system will be optimised to ensure that the decentralised combined heat and power concept is further developed for passenger ships. In another part of the project, consortium partners will work on a fuel cell system that is suitable for use on the high seas. To compensate for possible differences in the dynamics of fuel cells and onboard power supply networks, the energy supply will be buffered via a lithium-ion battery. Resource-saving sulphur-free diesel or second-generation synthetic fuels will be used to power the fuel cell equipment.

Besides purely technical challenges, overarching issues concerning ecological, technical and economic assessments of the application of fuel cells in ships will be addressed by *e4ships*. The involved parties work to uniform technical standards for system variations and performance classes. As soon as technical and regulatory hurdles to market maturity have been overcome, *e4ships* will be in the position to make a decisive contribution to the competitiveness of German dockyards and shipping lines through the provision of the necessary innovative and highly efficient technologies.

4 Fuel Cells in Special Markets

Before new technologies capture mass markets, they are often used in special applications that can showcase their merits particularly well. Under the NIP, this area is known as »Special Markets«. Fuel cell applications in these special markets stand out because of their greater proximity to market readiness compared to other application areas, their highly diverse applications — from micro fuel cells and critical power supply, to leisure and camping products — as well as a multitude of innovation-focused small to medium sized businesses involved. Critical power supply in various applications and industry fields (see Figure 2), conveyer technology, and vehicles such as forklifts and airport tow tractors, electric light vehicles like cargo bikes and boats, onboard power supply for the leisure and camping market, as well as small applications such as power supply for RFID systems (Radio Frequency Identification in logistics) on the basis of micro fuel cells, are just some of the diverse areas where this technology can be applied.

Figure 3: Fuel cells in critical power supply/ back-up power.

Following the NIP approach of clustering individual projects to enhance learning and communication among both academic and industry stakeholders, further lighthouse projects in the application areas of critical power supply and material handling are being prepared. In February 2010, for example, the *Bodensee* lighthouse project was started.

4.1 Bodensee Lighthouse Project

As a regional and thematic grouping for leisure applications of fuel cells, the *Bodensee* lighthouse project provides ideal conditions for the market preparation of fuel cell technology. By including operators (of e.g. boats and light vehicles), the public is offered a hands-on experience with fuel cell technology. Not only will the everyday suitability of sustainable and efficient products be tested, but public acceptance of new technologies will also be strengthened. That is why the *Bodensee* lighthouse project is particularly attractive for tourist-oriented regions, cities and communities, as well as for innovative institutions and businesses from the tourist, environmental and energy industries. Demonstrations will be focused initially in the Bodensee region, in Freiburg im Breisgau, and in the Danube city of Ulm.

Within the *Bodensee* project, the onboard power supply of camping vehicles (camper vans, mobile homes) and the power drive of leisure vehicles (boats, light vehicles) using fuel cell systems will be tested under everyday conditions. The goal is increased publicity, made especially feasible through fuel cell applications in this sector. The implementation of the *Bodensee* lighthouse project will be supported for a duration of one year by the state of Baden-Württemberg as a key partner. Various projects funded in the context of the NIP are part of the *Bodensee* lighthouse project. STEP is a project, where elcomax, SFC Smart Fuel Cell and Truma Gerätetechnik are developing and field-testing a new generation of membrane electrode assemblies (MEAs) for DMFC (direct methanol fuel cells) and HT PEM (polymer electrolyte membrane) fuel cells. Within the project »DMFC systems for light electric vehicles«, project partners Clean Mobile and SFC Smart Fuel Cell are developing a DMFC system platform tailored to the demands of the LEV (light electric vehicles) market segment. Optimisation and efficiency of the overall system of electric energy supply are at the forefront, as well as the demonstration of various LEV vehicle types in everyday use. A reformer fuel cell system will be further developed by Truma Gerätetechnik under the »Onboard power supply for leisure vehicles« project. The system will be subjected to a market-oriented practical test and deployed in the main independent onboard energy supply (auxiliary power unit) of leisure vehicles. The everyday testing is carried out by selected end customers and vehicle manufacturers.

The special markets area paves the way for fuel cell technology towards mass application. Here they demonstrate their reliable operation and the technological advantages of a future-oriented, sustainable, and cost conscious technology.

5 Conclusions

Hydrogen and fuel cell technologies will be key elements in future sustainable energy systems including transportation. Global efforts continue to introduce commercially viable products in this field as part of a broader portfolio of technological solutions.

Since the NIP began in 2008, more than 70 individual projects with more than 160 partners from industry and from academia were established in Germany addressing all industry sectors and markets in which hydrogen and fuel cell technologies have the potential to significantly reduce carbon dioxide emissions. The NIP combines focused R&D with comprehensive demonstration activities preparing the markets for all public and private stakeholders involved not only to address environmental issues, but also to strengthen their capability to remain at the forefront of innovations.

The structure to coordinate and manage the NIP with *NOW GmbH National Organisation Hydrogen and Fuel Cell Technology* as a strategic alliance involving public bodies (Government) and private organizations has proven to be efficient. Combining individually funded projects to form networks working commonly on overarching tasks, coherent communication, and fruitful international cooperation all help to leverage public funding and avoid doubling of private investments in the context of successful market preparation for hydrogen and fuel cell technologies.

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Fuel Cells and Hydrogen Joint Undertaking (FCH JU): A Public-Private Partnership for the Commercialisation of Fuel Cell and Hydrogen Technologies in the EU

Philippe Vannson, Interim Executive Director, EU Fuel Cells and Hydrogen Joint Undertaking

1 Summary

This paper describes the structure, research agenda and the current state of play of the Fuel Cells and Hydrogen Joint Undertaking (FCH JU). The FCH JU is a unique public private partnership at European level, bringing together resources and input from the European Community, European industry and academia. Since 2008, the FCH JU manages the large majority of the Commission's support to fuel cell and hydrogen technologies.

The objective of the programme is to accelerate the commercialisation of these technologies by implementing an integrated programme of breakthrough research, research and development and demonstration activities, complemented by a number of support activities necessary to achieve market introduction.

2 Policy Challenge: Technology for a Cleaner Energy System

Europe, like the rest of the world, is currently facing massive – and urgent – challenges in the field of energy policy. The pressing need to cut carbon emissions to combat climate change, but also growing energy import dependency and the depletion of oil reserves in the not too distant future mean that alternative, clean energy solutions must be not only developed but implemented on a large scale and without further delay.

In response to these challenges, the European Strategic Energy Technology (SET) Plan has identified key clean technologies needed to be developed for Europe to achieve its targets for 2020 - 20% reduction in greenhouse gas emissions; 20% share of renewable energy sources in the energy mix; and 20% reduction in primary energy use – as well as achieving the long-term vision for 2050 towards decarbonisation[1] Fuel cells and hydrogen are identified as playing a notably important role in the future energy mix. This is in line with the Commission's Communication, "Energy for a Changing World – An Energy Policy for Europe", the goals of the Lisbon Strategy and the European Council's Conclusion on a European Energy Strategy for Transport, 29 May 2007[2]

As with clean energy technologies more generally, the vested interests in conventional technologies, the scale of investment needed and high risks make the fuel cell and hydrogen promise an elusive one, if left only to market forces. However, public support alone does not bring about change – in the end, impact is brought about through markets only. Therefore, to accelerate the transition from a pre-market phase to commercialisation, coordinated action and use of resources between the public and the private sectors is crucial. Accordingly, European Industrial Initiatives – public-private partnerships – are a key tool identified in the SET Plan to accelerate the transition to a cleaner energy system by developing technologies ready for market.

To this end one of the earliest such initiatives has been established in the field of fuel cells and hydrogen: The Fuel Cell and Hydrogen Joint Undertaking.

3 Establishing the Joint Undertaking

In May 2003, the Hydrogen and Fuel Cell High Level Group, was established by the European Commission to study the way forward to implement fuel cell and hydrogen energy technology, as presented in its vision report, “Hydrogen Energy and Fuel Cells – A Vision of Our Future”. The report recommended the formation of a hydrogen and fuel cell public-private partnership in order to substantially accelerate the development and introduction to market of these technologies.

In December 2003, the European Commission facilitated the creation of a European Hydrogen and Fuel Cell Technology Platform (HFP), bringing together all interested stakeholders: businesses throughout the value chain, research institutes, academia and consumers as well as the European Commission and EU Member States. In March 2005, the HFP published a Strategic Research Agenda and Deployment Strategy, followed by an Implementation Plan in January 2007 setting out a comprehensive, long-term road-map for Europe.

This process confirmed that a coherent, long-term approach at EU level is essential for achieving critical mass in terms of scale, excellence and potential for innovation. The Commission’s proposal for a long-term public–private partnership under the 7th Framework Programme of the European Community (2007- 2013) in the form of a Joint Technology Initiative (JTI) on Fuel Cells and Hydrogen was a critical step in addressing the challenge ahead. In practical terms, this JTI was set up as a Joint Undertaking on the basis of Article 171 of the EC Treaty.

For the implementation of the Joint Technology Initiative (JTI) on Fuels Cells and Hydrogen (FCH) a Joint Undertaking[3] (hereinafter referred to as "FCH JU") was set up by a Council Regulation for a period up to 31 December 2017[4] The FCH JU is a public-private partnership composed of the European Communities, represented by the European Commission, the European Industry Grouping for a Fuel Cell and Hydrogen Joint Technology Initiative (NEW IG)[5] and the New European Research Grouping on Fuel Cells and Hydrogen (N.ERGHY)[6]. The FCH JU is an autonomous Community body. Its daily operations are implemented by a Programme Office, accountable to a Governing Board including representatives of all member groupings.

4 Structure of the FCH JU Programme

The FCH JU supports research, development and demonstration activities, as well as a number of support actions necessary for the objective of commercialisation, through annual, competitive calls for proposals. The work agenda is designed with industry in the lead in order best to identify gaps to be addressed on the way to commercialising the technologies.

In order to achieve the FCH JU objectives, as well as manage and implement the programme of RTD activities in an efficient manner, the Multi Annual Implementation Plan (MAIP) is divided into four main application areas (AA): Transport & Refuelling Infrastructure; Hydrogen Production & Distribution; Stationary Power Generation & Combined Heat & Power (CHP); and Early Markets. Cross-cutting activities have been established as a fifth area in order to emphasise their relevance and provide programme level coordination. These include Regulations Codes and Standards (RCS), Pre-Normative Research (PNR), socio-economic research, technology and life cycle assessments, market support (particularly for SMEs), public awareness and education. Important interfaces and synergies are expected between all these areas drawing mutual benefits from each other's results.

The structure of the plan reflects the RTD cycle and comprises long-term and breakthrough-orientated research, research and technological development, demonstration as well as support actions, including pre-normative research.

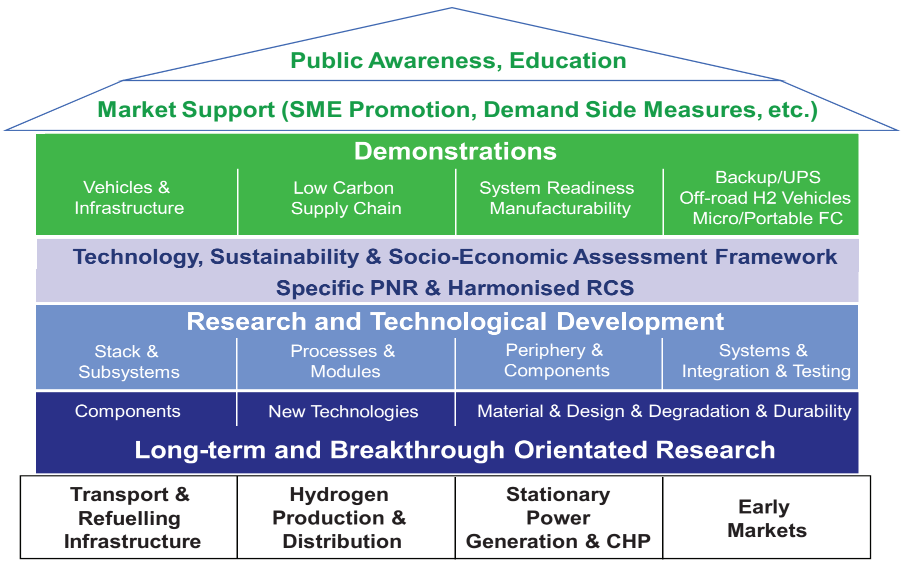

Figure 1: The structure of the Multi-Annual Implementation Plan.

The maximum EC contribution to the FCH JU for the implementation of the MAIP activities will be €450M for the period 2008 – 2013. The Industry is expected to at least match the Community contribution, bringing the total budget of the programme to nearly €1B. The initial tentative budget breakdown of the MAIP is shown in table 1. The rows of the table show the budgets for and reflect the proportional weight of the application areas and cross-cutting activities within the overall programme. The columns show the budgets for the different action categories and their relative shares.

Table 1: The initial tentative budget breakdown of the Multi-Annual Implementation Plan.

	FCH JU Funding by Action Categories					
Application Areas	Break-through research	Research & technological development	Demon-strations	Support actions	TOTAL	
					€m	%
Transportation & Refuelling Infrastructure	20-23	20-22	94-106	10-11	144-162	32-36%
Hydrogen Production & Distribution	17-20	16-19	12-15	0	45-54	10-12%
Stationary Power Generation & CHP	23-25	95-103	35-38	1	154-167	34-37%
Early Market		11-13	42-49	1	54-63	12-14%
Cross-cutting Issues				27-36	27-36	6-8%
TOTAL (€m)	60-68	142-157	183-208	39-49	450	
TOTAL (%)	13-15%	31-35%	41-46%	9-11%		100 %

The breakdown emphasises the key importance of Transportation & Refuelling Infrastructure as well as Stationary Power Generation & CHP for the overall programme. A substantial part of the budget is dedicated to Early Markets facilitating near-to-market applications that are important in achieving short-term commercial successes, and more specifically, supporting SMEs in their commercialisation efforts. The budget allocation for Hydrogen Production & Distribution will help to increase the share of sustainable hydrogen production based on renewable energy sources and to not only develop new but also improve existing hydrogen production methods. Cross-Cutting Activities are established as a separate budget category addressing the need for programme level actions on RCS, PNR, Socio-Economic Modelling and Planning, Technology Monitoring and Assessment, and Lifecycle Analysis, all being of key importance to the commercialisation objective.

Activities are divided between long-term and breakthrough research, research and technological development (which together total 44-50%), support actions and demonstrations. The strong role of demonstrations and market orientated actions reflects the growing technology maturity in “Transportation & Refuelling Infrastructure” as well as in “Early Markets”. These include proof-of-concept demonstrations for specific applications to attract additional industrial engagement, and extend the range of products and applications in the market. Demonstrations will deliver valuable experience and gain data from fleet operations, establish and test initial infrastructure elements including logistic and supply chains and increase customer awareness and acceptance. This will help to further mature technology, reduce investment risks and thus lay the foundations for mass commercialisation.

The focus of application areas “Stationary Power Generation & CHP” and “Hydrogen Production & Distribution” will be on long-term and breakthrough orientated research and research and technological development. This will enable the European research community and industry to address critical issues for these two application areas such as material durability, components reliability, large-scale manufacturing processes, sub-systems and systems design.

Approximately one tenth of the overall budget will be spent on support actions for the removal of non-technical, market barriers; particularly through the development of RCS, assessment of the socio-economic and environmental impact of the technologies, support to SMEs, public awareness and education. Some of the issues will be dealt with in the cross-cutting activities while others (e.g. LCA, safety "due diligence") will be implemented under horizontal activities in the different application areas or at project level.

5 Execution of the Work Programme: The Programme Office

The FCH JU Programme Office (PO) is in charge of the daily management of the Joint Undertaking and therefore executes all responsibilities of the FCH JU. It is accountable to the Governing Board including representatives of all member groupings of the FCH JU.

In its first years of existence, functioning under the European Commission in the interim, the Programme Office has had a dual role of on the one hand establishing the legal and financial infrastructure of the instrument that is the FCH JU while at the same time implementing the work programme. In addition, it has been charged with hiring the permanent staff, renting premises, the procurement of necessary IT infrastructure and setting up of other practical arrangements to run the programme.

In April 2010 the Programme Office had 12 staff and all the required conditions in place to implement its budget autonomously. Autonomy will bring the FCH JU the efficiency gains and increased flexibility of a smaller organisation that is one of the main rationales of this public-private policy instrument. In the meantime, the work of the Programme Office is gathering momentum and is moving forward in its mission to foster the commercialisation of hydrogen and fuel cell technologies by:

- Supporting the development of technologies in accordance with the Implementation Plans by granting awards following annual competitive calls for proposals;
- Advancing the commercialisation of key market segments through support and communication activities to raise awareness and increase the level of political support at the European and Member State level as well as public acceptance;
- Coordinating efforts and enhancing cooperation with and among other key stakeholders in Europe and further afield.

6 Supported Projects (2008 and 2009)

A total of 28.1M€ distributed among 16 projects was committed for the 2008 call for proposals. These projects have been started in January 2010 and are therefore in their preliminary stages. The list of projects is available on the FCH JU website: http://ec.europa.eu/research/fch/ and their breakdown is illustrated in the following figure:

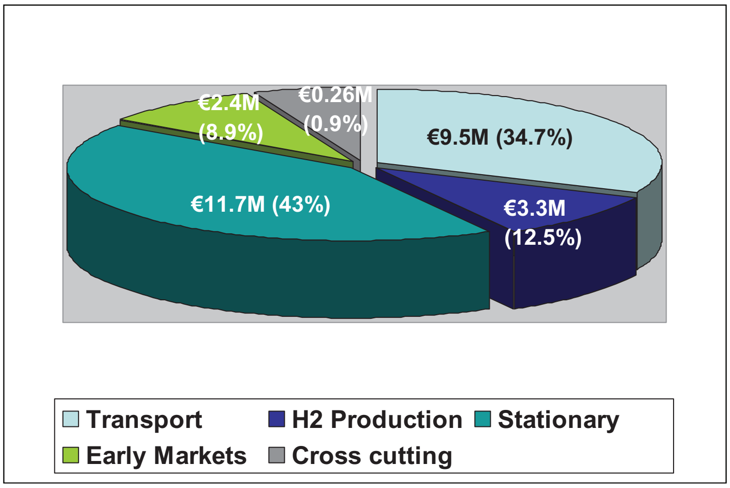

Figure 2: Breakdown of supported projects in the 2008 call for proposals by application area.

The available budget for the 2009 call for proposals was 71.3M€. This call, which closed in October 2009, received a total of 50 proposals for evaluation, out of which 31 passed the threshold. Further details from this call are shown in the next figure.

Proposals were evaluated soon after the submission deadline and notification letters were sent to applicants on 4 December 2009 along with their Evaluation Summary Reports. Soon after clarification letters requesting further information on aspects such as budget figures (including matching), SME declaration, registration/validation of the legal entities and membership of IG/RG were sent. Following responses and after conducting an analysis of the matching funds, a proposal is now ready for the Governing Board to approve a list of projects with which to start contract negotiations, as well as a reserve list of projects.

Application areas	Proposals submitted to evaluators	Proposals below thresholds		Proposals above thresholds		
		nb	%	nb	%	Requested FCH-JU contribution (M€)
Transportation & Refueling Infrastructure	7	**2**	*28.6%*	**5**	*71.4%*	38.33
Hydrogen Production & Distribution	7	**5**	*71.4%*	**2**	*28.6%*	4.75
Stationary Power Generation & CHP	21	**5 (6)**	*23.8%*	**15**	*71.4%*	34.86
Early Markets	7	**3**	*42.9%*	**4**	*57.1%*	14.27
Cross cutting Issues	8	**3**	*37.5%*	**5**	*62.5%*	2.35
TOTAL	**50**	**18**	*36.0%*	**31**	*62.0%*	**94.56**

Figure 3: Breakdown of submissions in the 2009 call for proposals by Application Area. [Note: One proposal in the Stationary Application Area was declared ineligible: no member from the IG/RG was included].

7 Supporting the Commercialisation of Key Markets for Hydrogen and Fuel Cells

In close cooperation with the Industry Grouping, the Programme Office is working to support the implementation of a commercialisation strategy for key market segments. The goal is to show a clear way forward towards the deployment and commercialisation of hydrogen and fuel cell technologies in those areas where they are of particular interest. This initiative follows the push from industry to show a clear commitment to the commercialisation of hydrogen and fuel cells, as exemplified by the letter from September 2009 signed by 7 leading OEMs.

Key market segments will be covered by a comprehensive and objective review of the state of the art, both as regards the technology status and in relation with other competing technologies. Following the outcome of this first phase, a roll-out scenario will be developed, possibly first in key areas or regions, followed by an expansion phase where other regions could also see increasing numbers of fuel cell units. This outline also needs to take into account: (i) funding needs; (ii) the ongoing initiatives by key regions and stakeholders and (iii) the need to share and disseminate information to stakeholders and the public at large to build up support.

One of the critical advantages in this process is the willingness of key industrial players, ranging from oil companies and OEMs through component manufacturers to end-users, to share their latest field data and to conduct an objective review by an independent body. This will enable these activities to obtain broader support than was previously the case and to gain additional momentum as hydrogen and fuel cells enter the first phase of commercialisation.

Some of the markets already identified as critical components in this commercialisation strategy include, but may not be limited to:

- Fuel cell cars: due to the importance of road transport in our energy mix, particularly through the use of private vehicles, it is critical to ensure that the way forward in the commercialisation of hydrogen and fuel cell cars is clearly addressed and delineated, in order to prepare properly and be able to meet the challenges that lie ahead.
- Fuel cell buses: this particular vehicle segment is believed to be an attractive initial market and stepping stone for broader adoption of hydrogen fuel cell based transport, due to limited refueling infrastructure requirements, and a well-defined user group with relatively uniform requirements in a relatively regulated environment.
- Certain early market applications, such as forklift trucks and backup power units, have seen increasing levels of deployment in recent years. Their potential to provide success stories by showcasing how they can compete in the marketplace with incumbent technologies makes these applications a critical component in the overall scheme to foster the deployment and commercialisation of hydrogen and fuel cells. As such, a proper strategy is required to ensure that these opportunities are not missed, while addressing gaps that may call for public support and actions.

8 Other Activities of the Programme Office

Aside from supporting projects following calls for proposals, the Programme Office of the FCH JU is also undertaking several other initiatives. The most important ones are:

- Preparation of the RTD programme for the call for proposals for 2010. The PO has been interacting with members of the NEW IG and N.ERGHY represented in each of the 5 Application Areas, i.e. Transport, Hydrogen Production and Distribution, Stationary, Early Markets and Cross Cutting, as well as the European Commission, in order to agree on a consolidated version that can be published in June 2010. The aim is to strike the right balance between demonstration and R&D activities, as well as among different Application Areas.
- Formal review of the Multi Annual Implementation Plan (MAIP). In particular, the targets for each Application Area should be revised in light of the latest developments in the technologies, as well as results from the first and preliminary results from the second call for proposals, which reflect the fact that certain topics did not attract project proposals and therefore cannot advance towards achieving those targets.
- Review of funding mechanisms. A thorough analysis of the functioning of the programme has been undertaken and options for amending the original European Council Regulation establishing the FCH JU are currently being assessed in order to increase the level of funding to all beneficiaries receiving grants in the calls for

proposals. The modification sought is not only intended to make the programme more competitive internationally and comparative to levels of support available for other energy technologies, but also to simplify programme management.

- Coordination of activities and cooperation with European stakeholders. Interaction with EU Member States and Associated countries through the States Representatives Group and European Regions represented by HyRaMP is being pursued in order to align activities and increase cooperation to make better use of the resources of all these contributors in Europe.
- International cooperation with partners outside Europe: International relations with countries such as the US and Japan have already been established and ways to develop this on a long term and more widespread basis are currently being explored.
- Communication activities, including the annual Stakeholders General Assembly, organised in 2010 in Brussels on 9-10 November.

9 Conclusions

The FCH JU has been established as a unique public-private partnership with the singular goal of advancing the commercialisation of hydrogen and fuel cell technologies. With the pivotal support and input both from the public and private sectors, it has structured its programme of research, development and demonstration activities in clearly defined application areas, as well as coordination and support actions that will cover numerous horizontal fields of interest. Industry lead and a ring-fenced budget of nearly €1B, contributed jointly by the Commission and industry partners, will set FCH JU aside from conventional research programmes to making a real and indisputable impact on accelerating the introduction to market of hydrogen and fuel cell technologies.

The budget of the FCH JU is being implemented through awards following open and competitive calls for proposals, with committed funds of 28.1M€ to 16 projects to date, and approximately 71M€ expected being committed in the following months to selected projects from the 2009 call.

The Programme Office, the executive arm of the FCH JU, is now ready to focus fully on its key mission after the initial establishment phase and will now be able to benefit from the increased efficiency and flexibility of a smaller organisation. It continues to increase its capabilities not only to execute its core tasks, preparing the next call for proposals for 2010 and executing the research agenda, but also addressing the non-technical barriers to commercialisation of fuel cell and hydrogen technologies.

The FCH JU is off to a good start bringing resources and capacities throughout Europe together to move from the pre-market phase to commercialisation.

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[2] COM(2007) 1 final

[3] http://ec.europa.eu/research/fch/

[4] Council Regulation (EC) No 521/2008 of 30 May 2008 setting up the Fuel Cells and Hydrogen Joint Undertaking; O.J. L 153, 12.6.2008, p.1

[5] http://www.fchindustry-jti.eu/; The NEW IG currently has 67 member companies across the EU. It is open to new members at all times.

[6] http://www.nerghy.eu/; N.ERGHY currently has 63 member universities and research institutes across the EU. It is open to new members at all times.

The U.S. Department of Energy's Fuel Cell Technologies Program

Dr. Nancy L. Garland, U.S. Department of Energy, Washington, D.C., USA

Abstract

This paper describes U.S. efforts to address energy security, economic, and environmental challenges. Within the U.S. Department of Energy, the Fuel Cell Technologies Program supports the broad national goals of reducing petroleum use, greenhouse gas emissions, and air pollution; developing a more diverse and efficient energy infrastructure; and creating high-skilled jobs in emerging technical fields. The FCT Program supports research, development and demonstration of fuel cell power system technologies for transportation, stationary, and portable applications. Key challenges to commercialization Fuel Cell Technologies Program Achievements will be described.

1 Introduction

President Obama has proposed a number of actions to help the United States address its energy security, economic, and environmental challenges. For example, final rules for increasing fuel economy standards for vehicles were recently unveiled by the Department of Transportation and the Environmental Protection Agency [1]. In October 2009, the President signed Executive Order 13514, Federal Leadership in Environmental, Energy, and Economic Performance. This executive order is focused on reducing the Federal Government's greenhouse gas emissions. Targets include reducing vehicle fuel petroleum use by 30% by 2020, requiring 15% of buildings to meet a set of guiding principles by 2015, and designing new Federal buildings to be zero-net by 2030.

Within the U.S. Department of Energy (DOE), the Fuel Cell Technologies (FCT) Program supports the broad national goals of reducing petroleum use, greenhouse gas emissions, and air pollution; developing a more diverse and efficient energy infrastructure; and creating high-skilled jobs in emerging technical fields. The goal of the Program is to enable widespread commercialization of fuel cells in diverse sectors of the economy, with emphasis on applications that will most effectively strengthen our nation's energy security and improve our stewardship of the environment. To achieve its goal, the FCT Program supports research, development and demonstration (RD&D) of fuel cell power system technologies for transportation, stationary, and portable applications. The key objective is to make fuel cells competitive with incumbent technologies and other advanced technologies in terms of lifecycle cost, performance, and market acceptance. The Program works with partners in industry, academia, non-profit institutions, and the national labs, and coordinates closely with other programs in other DOE offices, namely Science, Nuclear Energy and Fossil Energy.

The cost of fuel cells must be reduced and durability and performance must be improved to be competitive with existing technologies. As the cost of fuel cells comes down, through technological improvements and economies of scale, fuel cells will become competitive in a growing number of markets. Much of the program's work focused on automotive applications and PEMFC component research. Recent program changes led to an increased emphasis on near-term and mid-term applications.

2 Current status

Fuel cells have moved from the laboratory and into the marketplace. Currently, fuel cells are being sold in forklifts for material handling applications and for backup power particularly for telecommunications towers. For stationary and auxiliary power, more than 75,000 fuel cell systems have been sold worldwide and approximately 24,000 fuel cell systems were shipped in 2009, which represents a more than 40% increase over the number of units sold in 2008 [2]. For transportation fuel cell applications, there are currently 230 vehicles worldwide, with around 130 buses and around 200 refueling stations. Several manufacturers, including Toyota, Honda, Hyundai, Daimler, GM, and Proterra (buses), announced plans to commercialize vehicles by 2015 [3]. In 2009, Germany announced that it planned to develop a roadmap leading to a comprehensive nationwide infrastructure for hydrogen refueling, to be place in Germany by 2015 [4]. Partners in the "H2 Mobility" initiative plan for three phases: concepts for the expansion of new hydrogen refueling stations should be developed by 2011, next the infrastructure will be put in place, and finally fuel cell-powered electric vehicles will be on the roads by ~2015.

3 Benefits of Hydrogen and Fuel Cells

Electric vehicles provide many benefits with respect to reductions in greenhouse gas emissions and petroleum energy use. The benefits have been quantified using well-to-wheels analyses [5] that are based upon a projected state of technologies in 2020. The analyses show that conventional vehicles fueled by gasoline or natural gas generate the most grams of carbon dioxide equivalent per mile driven of all the technologies that were examined. For hybrid electric vehicles and for plug-in hybrids, those powered by renewable energy fuels generate the least greenhouse gas emissions. However, of all the technologies evaluated, the most benefits are obtained with fuel cell vehicles, in which vehicles powered by hydrogen fuel from electrolysis from central wind or nuclear high-temperature processes generate the least carbon dioxide emissions.

For petroleum energy use, conventional vehicles operating on gasoline consume the most petroleum energy per mile driven of all the technologies examined whereas conventional vehicles operating on natural gas consume much less. Hybrid electric vehicles and plug-in hybrids consume about one-third to one-half the petroleum energy per mile of a conventional vehicle. Note that those vehicles operating on a renewable fuel do require some petroleum to produce the renewable fuel. The most petroleum use savings per mile driven are obtained with fuel cell vehicles operating on hydrogen from fossil fuels (with sequestration) or from renewable resources.

4 Key challenges to commercialization

The Fuel Cell Technologies Program addresses both technology barriers as well as economic and institutional barriers to the commercialization of hydrogen and fuel cell technologies. The principal technical barriers include reducing the cost and increasing the durability of fuel cell systems as well as decreasing the cost of producing, delivering, and storing hydrogen. For consumer acceptance, the performance of hydrogen and fuel cell systems needs to be demonstrated under real-world conditions. Market transformation activities, especially procurement of fuel cell systems for federal facilities, are need to assist the growth of emerging markets, including achieving significant cost reductions through economies-of-scale. Codes and standards must be harmonized for global marketing and a robust, domestic manufacturing and supplier base must be established. Public awareness of hydrogen and fuel cell technologies must be increased. Last, a hydrogen infrastructure must be developed.

Innovative concepts have been proposed to establish an initial fueling infrastructure. DOE has partnered with the Southern California Air Quality Management District and the California Air Resources Board to develop a high temperature fuel cell system that generates combined heat, hydrogen, and power (CHHP) at the Orange County Sanitation District in Fountain Valley. CHHP systems can produce clean power and fuel for multiple applications. High temperature, molten carbonate fuel cells can operate on a variety of hydrocarbon fuels and the unit in Fountain Valley will operate on digester gas from a wastewater treatment plant. Key advantages of CHHP include the ability to readily locate the fuel cell system at industrial and commercial sites and the fact that additional reformation concurrently aids in cooling the fuel cell and uses waste heat from the fuel cell [6]. Improvements in design have led to higher H_2-recovery (from 75% to >85%).

5 Fuel Cell Technologies Program Achievements

The fuel cell sub-program is focused on reducing the cost and increasing the performance and durability of fuel cell components. The sub-program monitors the projected high volume cost of fuel cells as a gauge of the progress of the technology. The high-volume cost of 80-kW fuel cell systems for transportation applications is projected to be $61/kW, a more than 35% reduction in the last two years [7]. High volume production is defined to be 500,000 units/year. Since the initial volume of fuel cell vehicle sales will be likely be less than 500,000 units/year, one of DOE principle investigators, DTI, examined the cost of 80-kW fuel cell systems at different production rates. DTI reported that the cost drops from $229/kW at 1,000 units/year to $103/kW at 30,000 units/year.

The FCT Program is examining both near-term and long-term pathways for hydrogen production. The high-volume cost target to produce hydrogen (delivered and untaxed) is $2-3/gallon gasoline equivalent (gge). [The energy content of a gallon of gasoline is about the same as a kilogram of hydrogen.] For near-term pathways, the cost target was met with distributed natural gas reformation. Other near-term pathways such as hydrogen from bio-derived renewable liquids and electrolysis are projected to cost ~$4-6/gge. For the longer term pathways, the cost of hydrogen from biomass or coal gasification is also $4-6/gge whereas hydrogen from central wind electrolysis is $6-10/gge. Even longer-term pathways include hydrogen from solar high-temperature thermochemical cycles.

The Program is pursuing three pathways for hydrogen delivery including tube trailers, tanker trucks, and pipelines; the cost target for hydrogen delivery is $1/gge. Recent progress in new materials for tube trailers, advanced liquefaction processes, and replacing steel with fiber reinforced polymer for pipelines has led to 15-30% reduction in the cost of delivering hydrogen.

To increase the volumetric and gravimetric capacity of hydrogen storage vessels, DOE has focused on materials R&D and compressed/liquid hydrogen tanks. Compressed gas storage is a near-term opportunity for vehicle commercialization but reducing the cost of composite tanks is challenging; more than 75% of the cost of a tank is projected to be due to the carbon fiber layer. Carbon fiber is expensive. Materials discovery research is still needed for long-term, advanced storage technologies such as metal hydrides, surface adsorption, and chemical hydrides.

As mentioned previously, DOE is facilitating the development and adoption of codes and standards for hydrogen and fuel cells. Recent important key activities include the establishment of harmonized domestic and international fuel quality specifications. Educational activities to increase public awareness and understanding of fuel cells are an important part of the Program. DOE has conducted seminars and developed fact-sheets and case studies for end-users and conducted workshops to help state officials identify deployment opportunities.

Under its Technology Validation effort, DOE is validating the performance of hydrogen stations and fuel cell vehicles, under real-world conditions. More than 115,000 kg of hydrogen have been produced or dispensed and the fuel cell vehicles have travelled more than 2.3 million miles. Note that not all the hydrogen produced was consumed by the vehicles. Analysis of the performance data from the fuel cell vehicles by DOE’s National Renewable Energy Laboratory shows vehicle efficiency of 53 – 58% (>2x higher than gasoline internal combustion engines), vehicle range of ~196 – 254 miles, and fuel cell system durability of ~ 2,500 hrs (~75,000 miles travelled). Through the Technology Validation effort, DOE is also evaluating stationary fuel cells and real-world forklift and bus fleet data (in collaboration with the U.S. Department of Defense (DOD) and the U.S. Department of Transportation).

DOE’s Market Transformation activities address the Energy Policy Act (EPAct) of 2005. EPAct’s Section 783 directed the U.S. Federal Government to pay the incremental cost of fuel cells for stationary, portable, and micro fuel cells [8]. Government purchases of fuel cell systems could reduce the cost of fuel cells through economies-of-scale and help to support a growing supplier base. A recent study by Oak Ridge National Laboratory showed that a modest Federal acquisition program of fuel cells for material handling equipment and backup power (~2000 units per year) could enable cost reductions from ~$3500/kW to ~$1000/kW for fuel cell stacks in around 10 years [9].

Under the Market Transformation effort, DOE worked with the U.S. Department of Defense’s Defense Logistics Agency to deploy 40 forklifts at the Defense Distribution Depot in Susquehanna, Pennsylvania (DDSP). DDSP is the largest DOD distribution center under

DLA. DOE is working with the Federal Aviation Administration and the U.S. Army installing fuel cells for telecommunications applications and with the Joint Forces Training Center and the Marines to deploy fuel cells in fire stations. In 2009, DOE partnered with the Army's Construction Engineering Research Laboratory to install ~90 fuel cell systems for backup power at 13 locations across the country including Army Forts, NASA Ames Research Center, a Marine Corps Command Center, and Fort Sumter, a National Park Service facility. Finally, DOE is working with the Hawai'i Natural Energy Institute to use hydrogen for energy storage in a grid-integrated hydrogen system to mitigate variable electricity generation from renewable sources.

The America Recovery and Reinvestment Act (ARRA) was passed by the U.S. Congress in 2009 to create jobs and promote investment and consumer spending during the economic downturn. The FCT Program awarded more than $40M in ARRA funds for 12 projects to deploy up to 1000 fuel cell systems. The fuel cell systems will be used primarily for backup power and specialty vehicles such as lift trucks in warehouses, and also for portable power, combined heat and power, and auxiliary power units. The fuel cell systems will be used in as battery replacements for fleets of electric lift trucks at five existing distribution centers (Coca Cola, Kimberly-Clark, Sysco Foods, Wegmans, Whole Foods), deployed into the telecommunications and utility networks at AT&T and PG&E for backup power, and used as battery replacements for a complete fleet of electric lift trucks at an existing FedEx service center. DOE provided funding for R&D by all of the fuel cell suppliers involved in the ARRA projects showing continued support from the laboratory to deployment.

DOE works with many organizations to carry out its activities. Industry, universities, and National Laboratories carry out the applied RD&D needed to advance the technology. The U.S. Government's federal agencies cooperate through the Interagency Working Group to coordinate fuel cell R&D and through the higher-level Interagency Task Force for policy matters. International collaboration is harmonized through the International Energy Agency and the International Partnership for Hydrogen and Fuel Cells in the Economy. Activities at the local level are coordinated by state organizations such as the California Fuel Cell Partnership and the Connecticut Center for Advanced Technology. The FCT Program is reviewed periodically by the National Research Council and by the Hydrogen and Fuel Cell Technical Advisory Committee. The U.S. Council for Automotive Research (whose members are three U.S. automakers: GM, Ford, and Chrysler) and DOE partner through the FreedomCAR and Fuel Partnership; one of the objectives of the partnership is to examine and advance R&D of technologies leading to affordable hydrogen fuel cell vehicles and the hydrogen infrastructure to support them. The FreedomCAR and Fuel Partnership provides feedback to DOE on the Department's R&D activities, from the viewpoint of an automotive manufacturer.

Besides providing funds for fuel cell system deployments as described earlier, the ARRA provides financial incentives to encourage the installation of fuel cells and hydrogen fueling infrastructure. Some examples include: the Hydrogen Fuel Facility Credit increases the hydrogen fueling credit from 30% or $30,000 to 30% or $200,000, the Manufacturing Credit creates a 30% credit for investment in property used for manufacturing fuel cells and other technologies, and the Fuel Cell Investment Tax Credit increases the investment tax credit to 30%, up to $3,000/kW for business installations, and extends the credit from 2008 to 2016.

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Hydrogen Fuel Cell Vehicle and Station Deployment Plan: A Strategy for Meeting the Challenge Ahead – Progress and Next Steps

Cathrine Dunwoody, California Fuel Cell Partnership, USA

1 Introduction

In February 2009, CaFCP released the *Hydrogen Fuel Cell Vehicle and Station Deployment Plan: A Strategy for Meeting the Challenge Ahead.* The "action plan" is based on real-world learning and data, and details the major investments and actions needed to transition to a commercial market for fuel cell vehicles and hydrogen. The action plan has three primary areas of focus:

- Build retail hydrogen stations in the communities where passenger fuel cell vehicles will first be introduced.
- Support the expanding fuel cell bus program.
- Develop and implement the codes, standards, regulations and permitting processes that will enable the retail sale of hydrogen as fuel and adopt best-available fueling technology.

Commercializing fuel cell vehicles is a dynamic process. Actions and priorities will change as deployment proceeds, requiring refinements and adjustments as progress is made. The action plan identifies the need for ongoing review to adapt and refine strategies. This report presents the first such refinement by reporting progress and identifying immediate next steps required in 2010 and 2011.

2 Recent Progress

Most automakers have placed fuel cell vehicles with customers, and many plan to introduce fuel cell vehicles to the early commercial market around 2015. Transit agencies have been operating fuel cell buses in revenue service and are moving to next-generation technology. Customers have been fueling at private, fleet demonstration stations, and are awaiting a retail-ready network.

Since the release of the action plan in February 2009, CaFCP members have made progress toward commercialization, including the following examples:

Fuel Cell Vehicle Progress

- GM announced a fifth-generation fuel cell stack that is smaller, lighter and uses 50% less platinum. The new fuel cell stack is expected to have 120,000 miles durability[1].

- The Toyota FCHV-adv achieved an estimated range of 431 miles and an average fuel economy of 68.3 miles/kg during field evaluation testing with the federal government[2].
- The Honda FCX Clarity was named 2009 World Green Car at the New York Auto Show and Honda continues to lease vehicles to drivers in Southern California[3]
- Hyundai and Kia announced they will produce fuel cell vehicles within 2-3 years as part of their plan to develop more environmentally friendly vehicles[4]
- A Nissan fuel cell vehicle accumulated 100,000 actual road miles using the original fuel cell stack and components. Nissan also began its first North American customer demonstration program[5].
- Daimler is preparing for the global launch of 200 serial produced B-Class F-Cells in 2010 following 2.8 million miles of real-world driving with previous fuel cell vehicle demonstrations[6].
- UTC Power accumulated more than 5,000 operating hours on a fuel cell bus system[7].
- As fuel cell buses increased hours in operation and average monthly miles in several demonstration programs across the nation, they showed fuel economy improvement up to 141% when compared CNG and diesel buses[8].

Hydrogen Station Progress

- Five new retail-oriented stations were funded and began planning and design during 2009. (See Table 1)
- Several privately funded stations opened in the Los Angeles area. While providing fuel to limited fleet and retail customers, these stations supported technology development, expanded hands-on fueling experience and provided learnings about retail-like installations.
- The AC Transit hydrogen station in Emeryville received federal economic stimulus funds for solar panels to support production of renewable hydrogen[9].
- In March 2010, SAE International published TIR J2601, which establishes safety and performance requirements for gaseous hydrogen fuel dispensers[10].

CaFCP Bus Team participants and GTI developed the *Hydrogen Bus Fueling and Pressure Vessel Analysis* report to provide heavy-duty fueling input into the SAE J2601 fueling protocol standards development process.

- International standards organization ASTM published D7750-09[11], the first method specific to hydrogen fuel quality for fuel cell vehicles.
- California Department of Food and Agriculture, Division of Measurement Standards received $3.5 million from CEC AB118 funds to develop a type approval and field evaluation process for hydrogen dispensers, validate hydrogen quality analytical methods, and purchase and develop test equipment. These actions will enable retail sales of hydrogen as a transportation fuel.

Table 1: Public hydrogen stations funded in 2008 and 2009.

Station	Capacity (kg/day)	Pressure (MPa)	Expected opening date
Harbor City – Mebtahi	100	35/70	Q3 2010
Newport Beach – Shell	100	35/70	Q4 2010
San Francisco – SFO	120	35/70	Q2 2011
Torrance – Shell	50	35/70	Q3 2010
Westwood – UCLA	140	35/70	Q2 2011
Emeryville – AC Transit*	60 (passenger vehicles) 150 (transit)	35/70	Q4 2010
Fountain Valley – OCSD*	100	35/70	Q3 2010
Los Angeles – CSULA*	60	35/70	Q1 2011

* *– Station included in action plan*

Other Progress

- The National Renewable Energy Laboratory published updated composite data about the US Department of Energy National Hydrogen Learning Demonstration[12]. Hydrogen and fuel cell technologies have demonstrated excellent progress towards meeting DOE's goals[13].
- The International Partnership for Hydrogen and Fuel Cells in the Economy, with CaFCP, DOE and NREL, held a workshop focused on realistic, practical business issues faced by fuel retailers[14].
- UC Davis and UC Irvine published reports and released tools that provide analysis and planning guidance for hydrogen fuel cell vehicle commercialization, including station placement analysis, infrastructure network cost assessment and air quality and greenhouse gas emissions modeling[15] [16] [17] [18].
- The F-STEP program, California's emergency response training and education program for all alternative fuels, integrated CaFCP's hydrogen training materials for first responders, making it part of the state-wide training program for all fire departments.

3 Numbers of Vehicles

CaFCP conducts annual surveys of its automaker members to gain an accurate projection of planned vehicle deployments in the coming years. The surveys yield information that individual automakers would not normally make publicly available given the highly competitive environment of new vehicle development and commercialization. In December 2009 CaFCP conducted its second annual survey. The results show trends similar to the 2008 survey, confirming automaker plans for hundreds, thousands and then tens of thousands of fuel cell vehicles. Table 2 presents a summary of CaFCP's 2009 automaker survey results for passenger FCVs, which are consistent with CEC and CARB's recent automaker survey[19].

Table 2: 2009 CaFCP FCV Deployment Survey results: Passenger FCVs in operation.

	Hundreds	Thousands	Tens of thousands
	Through 2012	2013-2015	2016-2018
Total Passenger Vehicles*	450	4,200	54,300

** Total number projected on the road at the end of each timeframe*

In 2010, a collaboration of five San Francisco Bay Area transit agencies will begin operating a fleet of 13 fuel cell buses. SunLine Transit in Palm Springs and the City of Burbank will also operate fuel cell buses. To meet CARB's zero-emission bus (ZBus) regulation requirements, 10 California transit agencies are expected to start purchasing zero-emission buses as 15% of their fleet purchases in just a few years. Table 3 shows the number of fuel cell buses expected in each phase, based on the numbers required in regulation and transit agencies' reported plans.

Table 3: Number of fuel cell buses based on transit agency plans and ZBus regulation.

	Field Testing	Full-scale Demonstration	Commercialization
	2009-2011	2012-2014	2015-2017
Number of FCBs*	15 to 17	20 to 60	60 to 150

** Total number projected on the road at the end of each timeframe*

4 Next Steps: Position California for Success

CaFCP has identified specific steps that industry and government need to take in 2010 and 2011 to continue California's leadership in bringing fuel cell vehicles to the commercial market. Most prominent is the need to fund additional hydrogen stations so communities will be prepared and automakers can offer vehicles to more customers. It is important that government enable the retail sales of hydrogen as fuel, invest in early hydrogen infrastructure and better coordinate the regulations impacting fuels and vehicles. Steps are also needed to support the private sector as they develop viable business strategies for hydrogen fuel stations so future public funding can be reduced and ultimately eliminated. These and other actions are geared to support a launch of the commercial market in 2015. CaFCP plans to issue subsequent reports to detail additional needs and actions as commercialization proceeds.

4.1 Immediate station needs

The action plan identifies early market clusters in Los Angeles County, Orange County, Sacramento and the San Francisco Bay Area. CaFCP's 2009 vehicle survey confirmed that these communities will be the locations where automakers expect to engage their first fuel cell vehicle customers. The eight new hydrogen stations opening in the next year will support the first customers, but will fall short after 2011.

Automakers and transit agencies identified seven new stations needed in specific communities before 2012, and four existing stations that need upgrades, expansions or extended operations. Table 4 lists the locations of new and upgraded stations needed by the end of 2011.

Table 4: Additional hydrogen stations or upgrades/expansion immediately needed*.

County	Cluster area	Community	Operator	Capacity (kg/day)	Note
Los Angeles	Network connector	Burbank	City of Burbank	116	Provide O&M support
	Santa Monica	West LA	Shell	30	Expand capacity and pressure
		Santa Monica	*TBD*	*100*	*New station*
		Beverly Hills	*TBD*	*100*	*New station*
	Torrance	*Beach area (Redondo, Hermosa, Manhattan)*	*TBD*	*100*	*New station*
	Network connector	Diamond Bar	SCAQMD	12	Expand capacity and pressure
Orange	Irvine	Irvine	UCI	25	Expand capacity
		Irvine	*TBD*	*100*	*New station*
		Laguna Niguel/Hills	*TBD*	*100*	*New station*
Sacramento & Yolo	Sacramento	*Sacramento/West Sacramento*	*TBD*	*100*	*New station*
Alameda	Bay area	*Oakland (transit station)*	*TBD*	*180*	*New transit station*

Automakers identified these locations as best suited to provide “home” stations to their first customers, including existing stations that can be upgraded or expanded to meet customer needs. The goal is to maximize station utilization, make the best use of limited funding, and provide adequate fuel and convenience for customers. The current transit-only station in Oakland will close at the end of 2010 and a new station needs to take its place. If one or more of the recommended existing stations cannot be upgraded or expanded, a new station in close proximity will need to take its place in the network to successfully deploy vehicles.

These stations, along with existing stations and those in development, will provide sufficient fueling opportunities and convenience for the first customers. Stations within each cluster form a network that will enable customers to use a fuel cell vehicle as their primary vehicle. Specific locations are important in a small station network, as moving any one piece can impact the whole network. Figure 1 shows the locations of the California network in Northern and Southern California.

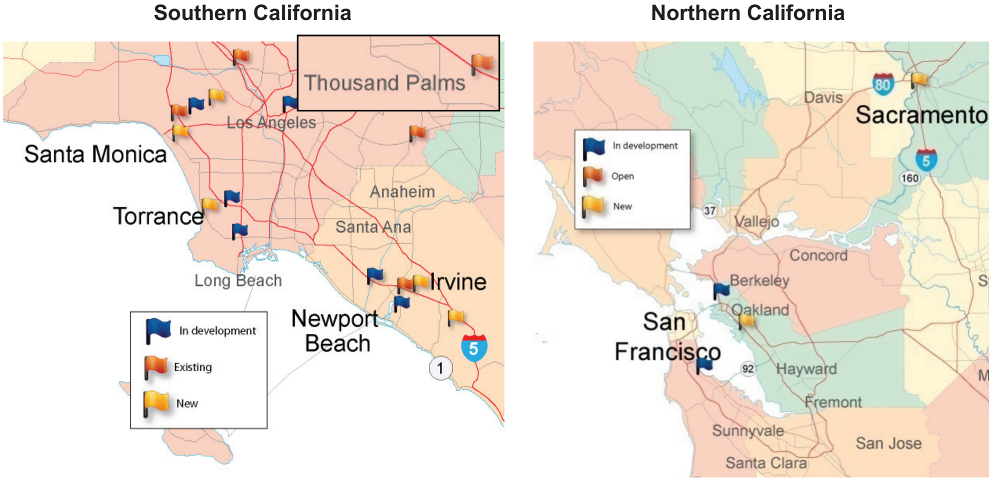

Figure 1: 2011 hydrogen station network.

Currently, hydrogen stations open 12-24 months from the funding date, meaning these 11 stations must be initiated immediately so they are open by the end of 2011. Infrastructure development funding, including the $22 million for hydrogen stations described in the *2009-2010 Investment Plan For The Alternative And Renewable Fuel And Vehicle Technology Program*, should focus on the locations listed in Table 4.

With each new round of stations funded and opened, and with more customers driving fuel cell vehicles, the network must grow and evolve. CaFCP will monitor progress and conduct annual surveys to identify gaps and opportunities in the station network. This dynamic process will help ensure that future funding, such as the $14 million proposed in the draft 2010-2011 Investment Plan[20], will be targeted toward the most important next investments and actions needed to move commercialization forward.

4.2 Retail station criteria

New and upgraded stations must be retail-ready, providing best-available commercial technology and a customer experience similar to (or better than) fueling at retail gasoline stations. CaFCP has defined these new stations as “showcase stations;” using practical retail criteria even as standards development organizations work to finalize commercial standards. Showcase stations offer:

- Retail customer experience—similar to existing gasoline/diesel/E85 stations, including reasonably priced hydrogen, no fueling agreements and locations near home or work.
- Right sized and ready for growth—capable of supplying at least 100 kilograms of hydrogen a day to provide sufficient fuel for the first customers and maximize throughput for the retailer. Growing vehicle deployments will strain supply, so new station capacities should increase over time and all stations should be expandable.

- Retail-oriented technology—the latest technology for dispensing hydrogen fuel, meeting current codes, standards and guidelines, including those published by SAE, ASTM, NFPA, DMS and others.

5 Additional Needs and Activities

Commercial launch in 2015 will require more than building stations. CaFCP members have identified other actions that need to be started or concluded in 2010 and 2011 to ensure successful rollout.

Synchronize and augment regulations and policies

As government increases focus on reducing greenhouse gas emissions, improving air quality and reducing dependence on petroleum, federal, state and local agencies are harmonizing regulations and policies and considering new ways to reach goals.

- The California Air Resources Board staff will propose renewable hydrogen regulations to the Board in October 2010; propose updates of the regulations for Zero-Emission Vehicles in late 2010 and Zero-Emission Buses in 2011; and evaluate how the Clean Fuels Outlet and other programs can be optimized to help ensure hydrogen and other alternative fuels are available to customers as vehicles enter the market.
- In 2010, through the Annual Merit Review and working with the International Partnership for Hydrogen and Fuel Cells in the Economy, the U.S. Department of Energy plans to continue coordinating information and learnings from fuel cell and hydrogen programs worldwide, including Germany, Japan and Korea, to promote early market commercialization of fuel cells for material handling, stationary power and vehicles
- The U.S. Department of Transportation, Federal Transit Administration, will finish the research and analysis phase of its Electric Drive Strategic Plan in 2010. The plan defines a five-year electric drive research plan in the context of a 20-year strategic outlook to provide guidance toward public transit electrification, including fuel cell buses.
- The California Energy Commission will issue their first solicitation for funding hydrogen stations by mid-2010 and will finalize their 2010-2011 Investment Plan supporting multiple fuel pathways, including hydrogen, to achieve the State’s energy and climate goals.

Complete codes and standards for retail sales of hydrogen

Codes and standards for all fuels and fueling technologies continue to be developed and refined. For hydrogen, it is important to finish the first codes and standards for fuel metering and quality so that hydrogen can be a retail fuel. CaFCP and its members will continue to participate in the standards development process with specific goals that include:

- The National Institute of Standards and Technology will propose changes to Handbook 130[21] and 44[22] in June 2010, enabling the National Conference of

Weights and Measures to approve these changes in 2011 and allow the retail sale of hydrogen.

- California Division of Measurement Standards, with support from NIST and the U.S. National Working, expects to finalize hydrogen metrology standards by 2011.
- ISO and SAE expect to publish draft hydrogen quality standards by late 2010.
- ASTM will publish supporting hydrogen quality analytical standards, in addition to those already published, and initiate round-robin testing with DOE by the end of 2010.

Support business models developed by the private sector

To be successful, all new technologies require a path to profitability that is self-sustaining and does not require support from government or ratepayers. CaFCP will continue to collect and share real-world information so stakeholders and entrepreneurs can begin developing business models for retail hydrogen infrastructure. In 2010 and 2011, CaFCP and its members will:

- Collect and distribute vehicle and station deployment data so current and future station owners can accurately project growing fuel demand.
- Conduct land surveys in early market communities to identify new station opportunities.
- Align hydrogen station technical information and real-world data with fuel retailers' needs so industry can develop business models for hydrogen as a transportation fuel.
- Identify synergies among fuel cells for material handling, stationary power and transportation that businesses can use in developing new models.
- Investigate long-term financing models that move away from government support toward private industry financing, including methods that other countries are using to build hydrogen infrastructure (e.g. infrastructure challenge grants, trust funds, tax exemptions, revenue bonds and/or public and private land donations).

Support early market communities

Hydrogen and fuel cell projects can help communities reduce environmental impacts, improve resource efficiency, use local renewable energy sources and develop green jobs. Increasing awareness and support at the local level will enable communities to develop these projects sooner. To support communities, CaFCP will:

- Refine and implement the Community Hydrogen Action Plan in the six early market communities identified in the action plan
- Work with other community-based groups and environmental organizations to provide information and coordinate activities
- Continue outreach and education of local leaders and the general public

6 Conclusion

CaFCP members have made significant progress toward the commercial launch of hydrogen fuel cell vehicles. FCVs have achieved range and performance comparable to conventional vehicles, developers have reduced size and cost, and some automakers have started serial production. The first retail-oriented hydrogen stations have been funded and are in development, with additional infrastructure funding expected by mid-2010. Standards development organizations have begun publishing codes and standards, public agencies began harmonizing regulations and policies, and universities have developed new reports and tools to further analyze and assess rollout strategies.

Progress must continue if California is to retain leadership in fuel cell vehicle commercialization, bringing environmental and economic benefits, including a potential 25,000 new jobs the DOE estimates the industry could create [23]. This report identifies actions needed in 2010 and 2011:

- Fund the identified seven new and four existing retail-ready “showcase” stations
- Synchronize and augment regulations and policies
- Complete codes and standards for retail sales of hydrogen
- Support business models developed by the private sector
- Support early market communities

Commercialization is a dynamic process that requires current information and effective communication among all stakeholders. CaFCP and its members are collaborating to inform, assess and refine future activities needed to stay on track towards the launch of a commercial fuel cell vehicle market in 2015.

7 Appendix A: Scenario for Hydrogen Station Rollout in California 2010-2011

The following table provides the retail station scenario for existing, upgraded, in development and newly proposed hydrogen stations outlined in this document. Details include expected supply in kg/day and the expected status of each station by the end of each year. Stations that are not open to all automaker vehicles or are expected to close in 2010 are not listed.

County	Cluster Area	Community	Operator	2010	2011	Pressure (MPa)	Capacity (kg/day)	Note
Los Angeles	Santa Monica	West LA	Shell	Open	Open	35	30	Expand capacity/ pressure
		Westwood	UCLA	Development	Open	35/70	140	
		Santa Monica		New	Open	35/70	100	
		Beverly Hills		New	Open	35/70	100	
	Torrance	Harbor City	Mebtahi	Development	Open	35/70	100	
		Torrance	Shell	Development	Open	35/70	50	
		Beach area		New	Open	35/70	100	
	Connector	Diamond Bar	SCAQMD	Open	Open	35*	12	Expand capacity/ pressure
		Los Angeles	CSULA	Development	Open	35/70	60	
		Burbank	Burbank	Open	Open	35/70	116	Provide O&M support
Orange	Irvine	Irvine	UCI	Open	Open	35/70	25	Expand capacity
		Irvine		New	Open	35/70	100	
		Laguna Niguel/Hills		New	Open	35/70	100	
		Newport Beach	Shell	Development	Open	35/70	100	
	Connector	Fountain Valley	OCSD	Development	Open	35/70	100	
Sacramento/ Yolo	Sacramento	Sacramento/West Sacramento		New	Open	35/70	100	
SF/Alameda	SF Bay Area	South San Francisco	SFO	Development	Open	35/70	120	
		Emeryville	AC Transit	Development	Open	35/70	60/ 200*	FCV and transit
		Oakland		New	Open	35	0/ 150*	Transit only
Other	Destination	Thousand Palms	SunLine	Open	Open	35	60/ 100*	
Total operational stations *(anticipated)*				**12**	**20**			

** FCV/transit supply*

Open – operational Development – previously funded and in development as of April 2010 New – proposed locations for 2010 funding

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Policy and Action Programs in Japan – Hydrogen Technology as Eco Technology

Prof. Dr. Hirohisa Uchida, Tokai University, Hiratsuka, Kanagawa, Japan

Summary

This paper reports an overview of policy and action programs for hydrogen technologies of Japan. Comprehensive and diverse action programs have been implemented by the NEDO (New Energy and Industrial Technology Development Organization). Various approaches to realize sustainable low carbon societies are being made also in local governmental levels. Saijo City, Ehime Prefecture, have been applying hydrogen storage technology to food production “Hydrogen Strawberry” and on-land fish breeding, and which has been found effective in CO_2 reduction and energy saving. Fukuoka Prefecture has reported effective CO_2 reduction and energy saving using the residential fuel cell system “ENE FARM” in a large scale. This paper concludes that hydrogen technology is human environment conscious technology - Eco Technology - which contributes to realize a sustainable low carbon society.

1 Japan’s Policy and Action Programs for FC and Hydrogen Technologies

1.1 Background

In 1999, the Japanese Government launched a strategic policy for fuel cell (FC) and hydrogen technologies. Since that time the government has booted up several strategic programs for energy innovation to realize sustainable development of Japan. By effective collaborations among governmental, academic and industrial sectors, the research and development (R&D) of FC and hydrogen technologies has yielded fruitful results in the development, introduction and diffusion of innovative clean energy technologies of FC and hydrogen.

Recent Japan’s energy self-sufficiency rate is 4% without nuclear power, or 20% with nuclear power. About 96% of energy demand of Japan is dependent mainly upon imported oil and uranium from foreign nations. The volatile oil price in the Middle East is violently threatening Japan’s fragile energy supply structure. The reinforcement of energy security is one of the prime issues for Japan. The R&D of clean energy and energy saving technologies are vital for Japan’s energy security.

As well known, our global environment is facing many serious issues such as global warming, climate change, desertification, acid rain, decreasing forest land, pollution of air, water, soil and sea, diffusion of chemical pollutants over countries etc. The CO_2 concentration in the atmosphere is said to be increasing at a rate of 600 to 900 tons-CO_2/sec, and other greenhouse gases emitted from our activity are assumed to contribute to global warming. Although other incredulous opinions are argued, we should avoid any possible dangerous factors which may threaten our global environment and our life. Japan will contribute to decrease of CO_2 emissions as the Japanese Prime Minister, Mr. Yukio

Hatoyama, addressed to the United Nations Summit on Climate Change that for the mid-term goal Japan will aim to reduce CO_2 emission by 25% by 2020 compared to the 1990 level [1]. If or not this would be possible, his words express Japan's strong intention and leadership in the fight and challenge on climate change and curbing CO_2 emissions. In Japan, 90% of the emitted greenhouse gas is CO_2. Therefore, the R&D of new energy technologies which contribute to energy saving and decrease CO_2 are the vital issue for Japan's energy policy. For the reduction of CO_2, the development of innovative new energy technologies such as FC and hydrogen technologies is needed. The Japanese Government has incorporated these new technologies into Japan's policy of energy security. The Japanese Government is implementing comprehensive R&D for FC and hydrogen technologies from fundamental to practical levels. In this paper, Japan's current action programs and activities in the R&D of FC and hydrogen technologies is summarized.

1.2 Action programs for clean energy technologies and low carbon society

In March 2008, a program for innovative energy technology - the Cool Earth - started. This program aims at efficiency improvement and low carbonization in the fields of energy supply side, energy demand side, and in the cross sectional field of the energy supply and demand sides as shown in Fig.1 [2]. The 21 key innovative energy technologies are selected with high priority. For these systematic R&D of clean energy technologies, the development of a new concept of the Japanese Smart Grid is included in the combination of solar, FC and battery technologies.

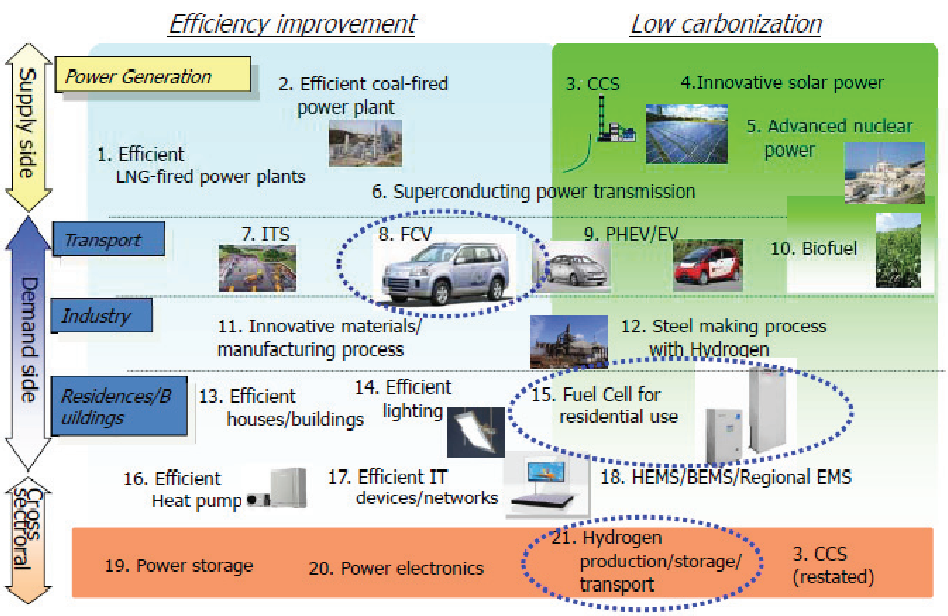


Figure 1: The 21 key technologies in the Cool Earth Program [2].

The Ministry of Economy, Trade and Industry (METI) is providing funding to NEDO which is acting as the center of operation and management of actual R&D projects among universities, companies and national research institutes. For these systematic R&D of clean energy technologies, the development of a new concept of the Japanese Smart Grid is included in the combination of solar, FC and battery technologies. Fig.2 shows comprehensive action programs of the R&D of FC and hydrogen technologies at NEDO until 2014.

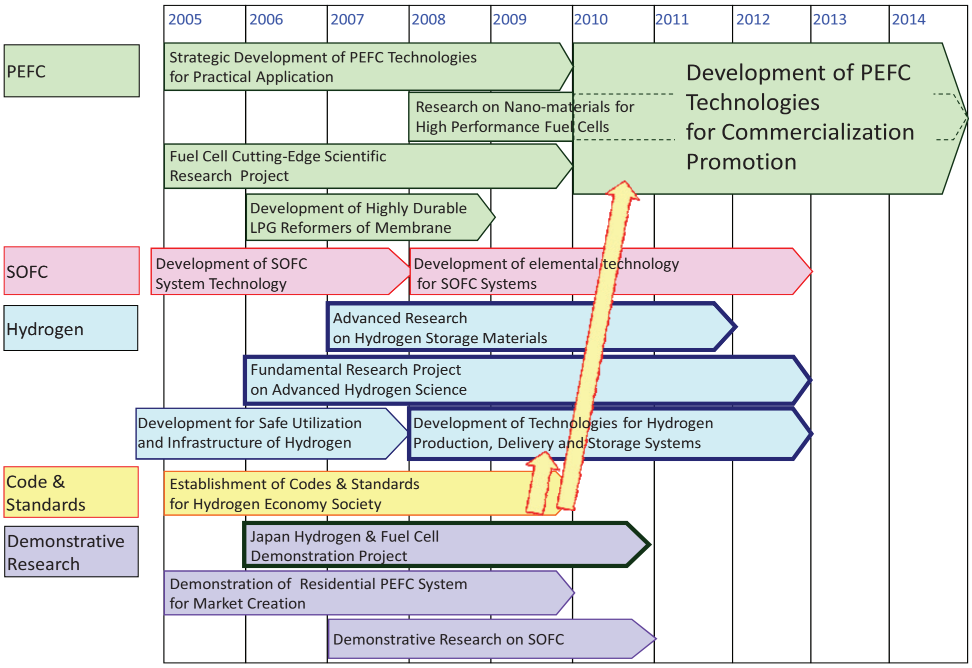


Figure 2: R&D on fuel cell and hydrogen technologies at NEDO [3].

Each project is being implemented with development of clean energy technologies as follows; **<PEFC>** Strategic development of PEFC technologies with basic research on materials for high performance practical applications / Development of standards for advanced application of FC / Demonstration of residential PEFC systems for market creation

<SOFC> Development of system and elemental technology, and demonstrative research on SOFC including residential use; **<Hydrogen>** Fundamental research on advanced hydrogen science - high pressure H_2, liquid H_2, H_2 tribology, H_2 embrittlement etc / Advanced research on hydrogen storage materials / Development of technologies for hydrogen production, delivery, and storage systems / Establishment of codes & standards for hydrogen society; **<Battery>** Development of high performance rechargeable battery for the next-generation vehicles such as hybrid electric vehicle, plug-in hybrid electric vehicle and electric vehicle.

1.3 Residential FC test and demonstration in a large scale

The demonstrative research of residential FC systems is exhibiting highly successful results. The demonstrative test of residential PEFC systems started in 2005, and more than 3,300 PEFC system units were tested at houses until 2008. In 2009, a residential model "ENE-FARM" producing electricity and hot water entered into market with an output from 0.7 kW to 1 kW, an electric generation efficiency of 35 % to 37 %, and a heat recovery efficiency of 45 % to 52 % at 337 K using liquid petroleum gas (LPG) or town gas. Each system unit is found to reduce 1.5 tons-CO_2/y. The price of this model ranges from 3.2 million yen to 3.46 million yen. Since 2009, 1.4 million yen per unit has been subsidized. Typical ENE-FARM system units by three manufacturers (ENEOS, TOSHIBA, Panasonic) are shown in Fig.3. Until the end of March 2010, around 5,000 units of ENE-FARM have been installed to houses. Very stable operational performance was confirmed through an operation of 2.159 x 10^7 h at the end of March 2009. The number of ENE FARM is predicted to expand from 750,000 in 2015 to 2,500,000 in 2030. A residential SOFC model with a higher electric efficiency of around 50 % and a higher operation temperature than 973 K is being tested as larger FC systems. Fig.4 shows a scenario for a market creation and commercialization of residential FC systems [4].

Figure 3: Typical residential FC system unit "ENE-FARM" [4].

Fukuoka Prefecture has demonstrated a successful "Hy-Life Project" in Fukuoka Hydrogen Town in which 150 residential FC systems have been tested at each house. Effects of 31 tons-CO_2/y reduction and 130,000 MJ/y primary energy saving were reported on March 2010.

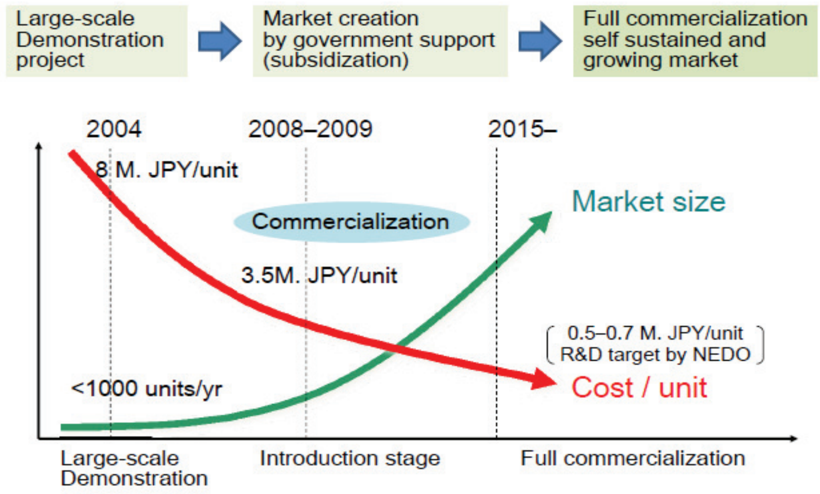


Figure 4: A scenario of development of residential FC system [4].

A hybrid residential FC system with a solar voltaic generation was commercialized in 2008, and a more marked effect of CO_2 reduction is anticipated together with conventional energy saving technologies.

1.4 Next-generation vehicles

The Japan's scenario of the commercialization of FCV is shown in Fig.5 [5]. This scenario was drawn by the Fuel Cell Commercialization Conference (FCCJ) under the agreement of the major Japanese companies involved in the R&D of FC and FCV. FCV will be commercialized in 2015 at the early stage, and 2050 in full commercialization.

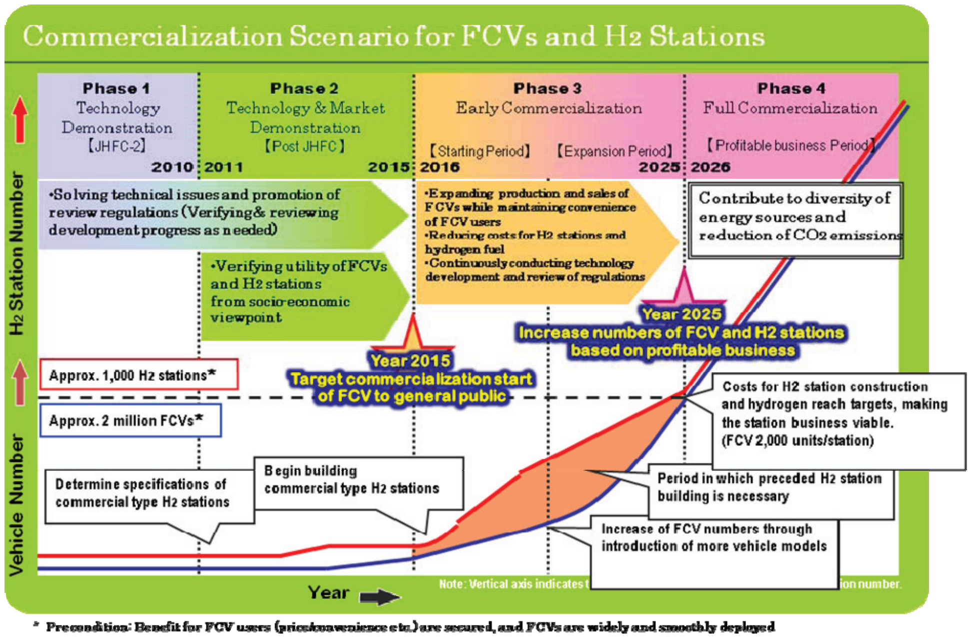
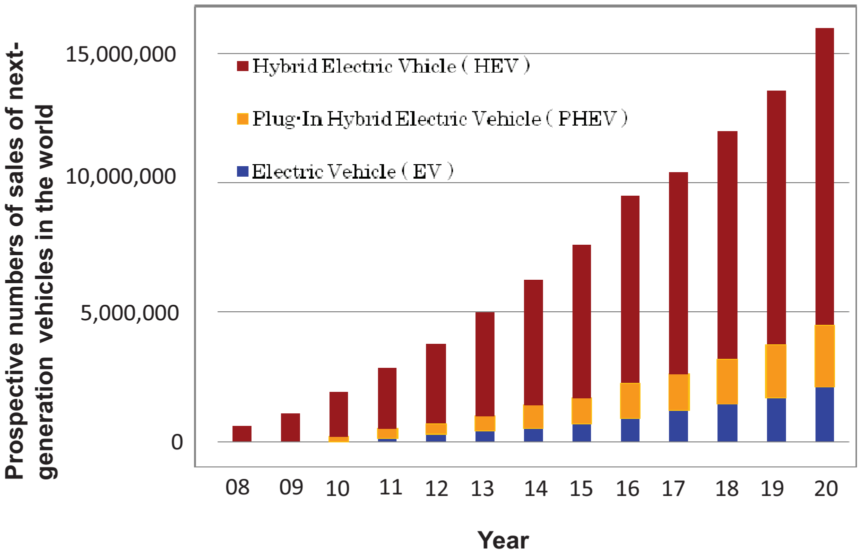


Figure 5: A scenario of commercialization of FCV in Japan [5].

This scenario becomes realized if preconditions such as cost reduction, improvement of reliability and durability for FC would be fulfilled, and hydrogen infrastructure such as the construction of enough numbers of H_2 fuel station and safety securement for FCV would be well developed.

Typical FC stacks for compact FCV have a weight less than 100 kg, and can start at 243 K and be operated at 373 K, 30 %RH. Strategic tasks to be solved for FC stacks are increasing durability longer than 5,000 h by improving membrane electrode assembly (MEA), and cost reduction by decreasing amount of platinum by 90 %. In this respect, basic research for used materials is vital for further development. As an example of a typical FCV, HONDA Clarity with its FC is shown in Fig.6. This FCV runs by a 100 kW PEMFC, and a high pressure H_2 tank (35 MPa H_2) with a volume of 171 Litter. The maximum speed is 160 km/h, the driving range is 380 km to 620 km, depending upon driving modes. The lease price is $600 per month for three years [6].

Figure 6: HONDA FCX CLARITY [6].



Reference data from Nikkei Business , 1st February 2010

Figure 7: Prospective numbers of sales of next-generation vehicles in the world [7].

The R&D of the next-generation vehicles such as hybrid electric vehicle (HEV), plug-in hybrid electric vehicle (PHEV) and electric vehicle (EV) are advancing. Fig.7 shows prospective numbers of sales of the next-generation vehicles in the world from 2008 to 2020 [7]. A rapid growth of the number of these vehicles is predicted in the next 10 years. About 20 % of the total number of vehicles will be dominated by the next-generation vehicles in 2020 [7]. Further development of new rechargeable battery like Li air battery is needed for the next-generation vehicles.

Vehicles with a hydrogen rotary engine are successfully developed. Fig.8 shows MAZDA RX-8 Hydrogen RE with a dual fuel system driven by either the H_2 gas (35 MPa) or gasoline [8]. The maximum output power is 80 kW and driving range is 100 km by hydrogen, and 154 kW and 549 km by gasoline, respectively. This vehicle has been contributing to HyNor Project, Norway, since 2007 [9].

Figure 8: MAZDA RX-8 Hydrogen RE vehicle and the H_2 rotary engine [8].

1.5 Fundamental research on materials for innovative technologies

As these comprehensive R&D projects have been advancing, it is found that more precise and exact information on the behaviour of hydrogen and relevant elements on/ in materials under various conditions is needed in order to develop innovative, practical, durable and reliable systems. In Japan, a special fundamental research project “Advanced Fundamental Research on Hydrogen Storage Materials: HYDRO-STAR” was launched in 2007. In this project, basic research for hydrogen storage materials is actively being conducted. Under the motto “Back to the basic”, several basic research programs for FC and hydrogen technologies are advancing: Research Centre for Hydrogen Industrial Use and Storage (FY2006-2012), Basic Materials Research for High Performance Fuel Cell (FY2008-2014).

2 Hydrogen Technology

Hydrogen technology can be divided into two types. The first one is hydrogen consuming technology such as FC systems, and internal hydrogen combustion engines. In these systems, hydrogen reacts with oxygen to produce water, and in which chemical energy is converted to electric or mechanical energy. In this technology, the price of H_2 production is essential and predicted as 80 yen/Nm^3 (2010), 80-40 yen/Nm^3 (2015) and below 40 yen/Nm^3 (2020) [10].

2.1 Hydrogen storage

In the second type, hydrogen is not consumed, but acts as a media of energy conversion or carrier in such systems as heat pump, nickel-metal hydride (MH) rechargeable battery, and mechanical actuator where hydrogen storage materials play crucial roles [11,12]. The fundamental reactions of hydrogen absorption and desorption of a hydrogen storage alloy are shown below,

M + H_2 (H^+) => MH + Q : Exothermic H_2 absorption (hydriding)

M + H_2 (H^+) <= MH - Q : Endothermic H_2 desorption (dehydriding)

where M is hydrogen storage alloy, H_2 is hydrogen gas, H^+ is hydrogen ion, MH is metal hydride, and Q is reaction heat. These simple reactions can be applied to practical hydrogen technologies. A hydrogen storage alloy absorbs and stores hydrogen atoms in a higher density in the metal lattice than in the liquid state of H_2. This feature is applied to hydrogen storage tanks. Based on the NEDO's road map of hydrogen storage technology for FCV and H_2 station, various metallic, carbon and organic materials have been examined. The recent R&D on the storage materials are being implemented in the HYDRO-STAR project [13]. New materials should have a higher H_2 storage density than 6 to 9 mass% below 423 K, a storage capacity over 90 % of a maximum capacity after 1,000 cycles, and a cost less than 1,000 yen/kg. A hybrid use of H_2 gas and hydrogen storage materials in a H_2 container is anticipated to H_2 station and transport.

The hydrogen storage alloys are used for negative electrode of Ni-MH batteries which have been used for hybrid vehicles like TOYOTA PRIUS. Compared with conventional Ni-MH batteries, new Ni-MH rechargeable batteries like SANYO ENELOOP and Panasonic EVOLTA exhibit markedly low self-discharge rates. Almost 80 % of the full charge capacity remains after one year. Charge and discharge of these batteries can be made over 1000 to 1200 cycles. The successful commercialization of these batteries were realized as a result of fundamental research on electrode materials such as alloy lattice modifications (super lattice hydrogen storage alloys) or alloy microstructure modifications.

2.2 Heat reactions of hydrogen storage alloys

A hydrogen storage alloy releases heat Q in the hydride MH formation by H_2 absorption, and absorbs heat Q from the surrounding by H_2 desorption in the hydride MH decomposition. By combing two different hydrogen storage alloys, M_a and M_b, connected with a closed pipeline. By applying high temperature waste heat from factories or incinerators to a hydride M_aH, H_2 is desorbed from M_aH. The released H_2 gas moves to M_b and forms a hydride M_bH. When MH_b desorbs H_2, which is moving back to M_a, M_b absorbs heat from surroundings. Using a heat exchanger, this heat absorption reaction of M_b can be applied to decrease the ground water temperature at a level of 293 K to 273 K by repeated H_2 absorption and desorption reactions. The temperature can be decreased to as low as 243 K in the use of a refrigerant instead of water [14]. The MH freezer can be driven by the combination of waste heats with high (>433 K) and low (300 K) temperatures. This is an effective use of waste heat when the fact is taken into account that about 60 % to 70 % of the primary energy is generated as waste heat to surroundings. This MH freezer system has been applied to produce cold water for food production and on-land fish breeding in a large scale in a local city, Saijo, Japan.

2.3 Application of MH freezer to food production

The policy of clean energy by the Japanese Government has been extending to local areas in Japan. Saijo City, Ehime Prefecture, Japan, set up a MH (Ti-Zr based alloys) freezer system (2.5 USRT) in 2001 by the support of the METI, Advanced Industrial Science and technology (AIST), and Japan Steel Works, Ltd [12]. Using this MH freezer, the temperature of two rooms was cooled down to 243 K and 273 K, respectively. Compared with conventional CFC freezers, the MH freezer reduces the energy consumption and the CO_2 emission by 70 %. The city initiated a project “Saijo Cool Earth Project” in 2009, and introduced additional four MH freezer systems (1.2 to 1.5 USRT) for cold water production with temperatures from 273 K to 278 K. The cold water has been used to the cultivations of strawberry (“Hydrogen Strawberry”) and the on-land fish breeding. This application has demonstrated that strawberry can be cultivated all the year round, resulting in increase twice in production amount and income compared with usual cultivation way without the MH freezer. The MH freezer has been applied to control of temperature of on-land fish breeding in Saijo City. Compared with conventional electric chillers, the MH freezer system reduces 25.6 tons-CO_2/y for a field of 1000 m^2 strawberry cultivation, and 38.5 tons-CO_2/y for fish breeding tanks with 20 tons of water. Furthermore, CO_2 produced from an oil refining factory was spread into the strawberry house to facilitate photosynthesis of the cultivation. This resulted in a reduction of 3.6 tons-CO_2/y. In addition, a solar photovoltaic system, which supplies electricity to control electric valves and motors of the house and breeding tanks, reduces 6.3 tons-CO_2/y. As the overall effect in the application of the MH freezer systems, 74 tons-CO_2/y reduction and about 90 % of electricity consumption were confirmed. Saijo City will expand the MH freezer technology to other agricultural and fishery fields, and connect to employment action, and the realization of a sustainable low carbon society

3 Hydrogen Technology as Eco Technology [14,15]

Environment means not only natural surroundings like water or air, but more. We should recognize that our sense of values and ethics vary and are strongly influenced by his/her environment, i.e., family, community, country, tradition, culture, religion, economic and political system, and so on. In this respect, we should use the expression “Human Environment” with great diversity of sense of values, instead of “Environment”. Sustainability may be carried out from generation to generation only if people can feel comfortable or any merit. Traditional science and technology have served the kingdom of universality, objectivity and rationality. However, this has not been comfortable for us because we are living in the diversity of the natural environment, locality, and human environment surrounding us. At present, various renewable energy systems are developed and applied in each local area. This seems quite natural in accordance with our diverse human environment. Hydrogen may be applied not only to FC but to various purposes like agriculture and fishery. The high diversity of hydrogen technologies may serve our diverse requirement and environment.

From this point of view, hydrogen technology may be considered as “Human Environment Conscious (=Eco) Technology”.

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The Electrification of the Powertrain at Honda, an approach towards sustainable mobility

Toyohei Nakajima, Senior Vice President of Honda R&D Europe (Deutschland) GmbH, Offenbach am Main, Germany

Abstract

Honda's approach towards sustainable mobility is described by wide spreading the Honda Integrated Motor Assist System, a hybrid powertrain system applied to not only the most recent models at Honda such as the new Insight and CR-Z but since more than 10 years to all our hybrid vehicles and further by showcasing the FCX Clarity Fuel Cell Electric Vehicle innovation including degradation analysis and innovative V-flow stack structure as well as infrastructure research such as solar powered hydrogen station and cogeneration unit.

1 Introduction

Ladies and Gentlemen,

Honda's vision for personal mobility for the next 100 years of mobility calls for an accelerated shift away from fossil fuels, and for the early development of technologies that will reduce greenhouse gas emissions to zero. This is because continuing growth in the world's population is likely to result in continuing growth in the demand for mobility.

Honda's vision for the sustainable mobility society of the future is based on the concept of mobility that uses energy generated by Honda technology. However, this will not be an easy goal to achieve. We will need to overcome challenges far greater than anything we have experienced in the past. Honda is determined to meet these challenges and realize this vision by accelerating initiatives in response to environmental problems.

In the Energy Technology Perspective Report 2008 of the International Energy Agency, the generated Blue Map scenario targets at reducing global CO_2 emissions to half the 2005 level by 2050. This means that Blue Map emissions will have to be at least one forth the baseline emissions of 62 Gt in 2050.

In order to reduce total CO_2 emissions to half of the current level by the end of the forecast period until 2050, the society must work as a whole. For example, by widespread expansion of low or zero carbon fuels or electric power as well as highly efficient transportation using multiple energy carriers.

The transport sector will be forced to make tremendous efforts to reduce CO_2 emissions to a level of 12.5 Gt by 2050. This scenario could be realized only when we improve the internal combustion engines, promote electrification technologies such as hybrid and EV, and widely adopt bio-fuel and hydrogen fuel cell electric vehicles.

In addition to continuous efficiency improvement of internal combustion engines, hybridization has just entered the phase of engineering improvement targeting wide use.

Research is being accelerated for further electrification including plug-ins.

Research is also conducted for battery electric vehicles and range extender electric vehicles.

However, there still are technical challenges such as energy density. These challenges cannot be managed by engineering efforts alone, but also science.

Fuel cell vehicles still have issues such as durability and cost which need to be overcome and in the latter to be dramatically reduced.

Internal combustion engines must be continuously improved for efficiency. Research of highly efficient engines such as HCCI are progressively carried out considering the recent move toward the use of biofuels and synthetic fuels.

Gasoline and diesel engines are moving towards downsizing and HCCI, PCCI for further efficiency improvement.

Efforts are being made targeting both high efficiency and affordability.

Taking advantage of various fuels including biofuels, working together with the fuel production side may lead to a totally new concept of technology with best matching of fuel and engine for optimum efficiency.

2 Hybrid Technology Evolution

Honda original Insight was the first introduction of hybrid car in the world in 1999. Now launching our 6th all-new hybrid vehicle, Honda has a long experience to fully understand customers' wants and needs when it comes to hybrid technology.

Honda was the first to have 3 hybrids vehicles available and the all-new CR-Z is the latest symbol of our commitment and what's to come – a portfolio of hybrids intended to serve different needs and tastes of consumers.

The CR-Z will be joined soon by a small hybrid car based on the Jazz in Europe.

With the Civic Hybrid, the new Insight, and the CR-Z, we expect to grow Honda's European hybrid sales to several times their current level further advancing the fuel efficiency leadership of the Honda brand.

Honda has a clear and defined hybrid story for the next 5 years.

The inspiration behind the CR-Z was to create a new type of car that offers a sporty driving experience, combined with the environmental responsibility of a petrol electric powertrain, wrapped in an aerodynamic coupe body.

The overall power output of the engine and IMA system is 91 kW at 6100 rpm combined with a healthy 174 Nm of torque at just 1,500 rpm. The peak torque figure is identical to that of the 1.8-litre Civic and arrives at just 1,500 rpm, a level where previously only turbocharged engines deliver their maximum.

Even with torque levels directly comparable with a Civic, the CR-Z emits 35 g/km less CO_2 Other harmful exhaust emissions are also very low and the Nickel Metal Hydride battery pack can be recycled through Honda dealers, at the end of the vehicle's life.

3 FCX Clarity Innovative Technology

Let us elaborate how various forms of powerplant electrification help decrease CO2 emissions.

Firstly, the internal combustion and hybrid vehicles both offer a very long driving range. They also offer quick refuelling capability.

Then, depending on the system configuration, the plug-in hybrid vehicle can offer zero CO_2 emissions when driven on electric power alone but only for a limited driving range.

Thirdly there are the Battery Electric Vehicles. Although they emit no CO2 emissions, they are limited by their short range. To extend their range, there are now many ideas being considered, from quick charging to battery swap.

And finally we have fuel cell electric vehicles.

As you may already be aware, hydrogen fuel cell vehicles combine a long driving range with significant reduction in CO_2 emissions.

With the development of the required hydrogen station infrastructure, mobility as we know it today can become fully sustainable.

Honda’s research on fuel cells goes back to the late 1980’s.

In December 2002, in what was a world first, Honda started leasing the FCX.

This FCX incorporated many already well-established Honda automobile technologies such as:

- Advanced motor technology from the Honda EV PLUS electric vehicle which was introduced in 1996 much earlier than currently in the electric vehicle hype.
- High-pressure tank technology from the Civic GX natural gas-powered vehicle.
- Energy management technology from the first generation Honda Hybrid Insight and other hybrid vehicles which have followed.

The heart of the powerplant is the fuel cell stack and its evolution over time.

- First came a material evolution from 1999 to 2003, with switching from fluorine to aromatic electrolytic membrane material for a wider operating temperature range.
- At the same time, we switched from carbon-based to metal-based separators to prepare for future mass production.

The fuel cell stack evolved again in 2006 with the adoption of a new design structure.

In this latest evolution, it has a ‘V Flow’ cell structure featuring ‘Wave Flow Channel’ separators. The result is a lighter, more compact, 1-box stack construction.

These are the key factors and related countermeasures for occurring stack degradation.

Through almost endless efforts to analyze and improve the degradation we have accomplished a big improvement of the Fuel Cell stack which is applied to current Honda FCX Clarity.

We will continuously improve not only the performance of the fuel cell stack but also our capability of the detail analysis for the key area such as degradation and others.

4 Hydrogen Infrastructure Research

In January 2010, Honda began trials of a next-generation solar hydrogen station, which will produce hydrogen from water using electric power produced by solar cells. The station’s solar panels are based on original Honda technology, and could potentially be used in household hydrogen supply systems in combination with a new hydrogen production system that dramatically reduces power consumption during hydrogen production and storage.

The latest generation of a PV-Electrolyzer-Hydrogen station is designed to supply high pressure hydrogen without using a compressor. Designed as a single, integrated unit to fit in the user's garage, Honda's next generation Solar Hydrogen Station is reduced in system size, while producing enough hydrogen (0.5kg) via an 8-hour overnight fill for daily commuting (10,000 miles per year) for a fuel cell electric vehicle.

The previous Honda Solar Hydrogen Station system required both an electrolyzer and a separate compressor unit to create high pressure hydrogen. The compressor was the largest and most expensive component and reduced system efficiency. By creating a new high differential pressure electrolyzer, our Honda engineers were able to eliminate the compressor entirely. This innovation also reduces the size of other key components to make the new station the world's most compact system, while improving system efficiency by more than 25% (value calculated based on simulations) compared to the solar hydrogen station system it replaces.

Compatible with a "Smart Grid" energy system, the Honda Solar Hydrogen Station would enable users to refill their vehicle overnight without the requirement of hydrogen storage, which would lower CO_2 emissions by using less expensive off-peak electrical power. During daytime peak power times, the Solar Hydrogen Station can export renewable electricity to the grid, providing a cost benefit to the customer, while remaining energy and thus CO_2 neutral.

Besides that, research in Natural Gas based reformer systems to produce hydrogen in a very efficient manner has been conducted including combined heat and electric power supply. Home Energy Station IV, is the 4^{th} generation prototype model and was operated to verify both hydrogen supply to FCX and power generation that can be interconnected with the commercial power grid.

Verification tests demonstrated that this is a new energy supply system format that can simultaneously reduce the environmental by significantly lowering CO_2 emissions load while providing merits to the user by reducing total energy cost.

5 Summary

To reduce CO2 emissions from automobiles, internal combustion engines such as gasoline and diesel engines are being made more efficient but there are limitations to such efforts.

Accordingly along with the improvement of engine efficiency, technical efforts are directed towards developing electric drive vehicles such as hybrid, EV and Fuel Cell Electric Vehicles.

Considering the Fuel Cell Electric Vehicle being the ultimate car, Honda has been continuing research and development to prepare this vehicle for widespread use.

Fuel Cell Electric Vehicle performance has been improving steadily to date, but there still is a hurdle we have to clear before its commercialization. That is, FCEVs must realize cost, durability and reliability comparable to gasoline-fueled vehicles.

As explained for cost-related issues, we must also refine a wide variety of related element parts, moving a step higher each time.

Regarding durability and reliability, real-world feedback is vital, in addition to quality assurance technology in production. We will make step-by-step efforts to tackle this challenge as well.

Recently we have conducted long run test of FCX Clarity in Japan from Utsunomiya where our Automotive R&D center is located to Aichi prefecture without recharge of hydrogen fuel thorough the range of more than 510 km.

Refueling time is around 3 to 4 minutes which is relatively practical time compared to conventional ICE engines.

Honda is working hard developing FCEVs that can be put to widespread use.

In Japan there started the FCCJ which stands for Fuel Cell Commercialization Conference of Japan and investigates the commercialization scenario and hydrogen stands towards 2015 deployment of the FCEV to the Japanese market.

Honda has been striving to keep blue sky for children and tackle environmental issues since CVCC engine was invented from more than 30 years ago.

We will make more efforts to approach towards sustainable society and create innovative technology further for our society and customer.

Thank you.

Comparison of Batteries and Fuel Cells for Electric Mobility

Dr. Andreas Dorda, Austrian Federal Ministry of Transport, Innovation and Technology (BMVIT), Vienna, Austria
Christoph Panwinkler, Dr. Stefan Winter (A3PS), Austria

Summary

Electric mobility is more than just battery electric vehicles. The wide range of vehicle classes and application areas require different electric vehicle technologies (hybrid, battery electric and fuel cell vehicles). The development proceeds from the micro and mild hybrids, full- and plug-in-hybrids to battery electric and fuel cell vehicles. As each technology has its strengths and weaknesses we will find a wide range of solutions for sustainable mobility in the near future. In order to introduce sustainable mobility the Austrian Federal Ministry of Transport, Innovation and Technology (BMVIT) supports the development and market introduction of alternative propulsion systems and fuels by a wide spectrum of funding programs and instruments. Funding has been increased up to 60 Mio. € in 2009 and 2010. In addition to the financial support the BMVIT founded the Austrian Agency for Alternative Propulsion Systems and Fuels (A3PS) as a strategic cooperation platform with the industry and research institutions.

1 Introduction

Tightening emission standards for pollutants, greenhouse gases and noise favour the market introduction of alternative propulsion systems. The EU has set the goal to reduce greenhouse gases by at least 20% until 2020 as of 1990. Therefore it is necessary to increase energy efficiency and to push renewable energy sources not only but particularly in the transport sector. To do so, ecological vehicles have to be developed and introduced to the markets in large quantities. Ecological vehicles are characterized by a low environmental impact throughout the whole life cycle. They have low air pollutant and noise emissions and run on low-carbon energy sources. Considering the whole life cycle ecological vehicles finally must be easy to recycle. Among the wide range of different drive train solutions Battery Electric Vehicles (BEV) and Fuel Cell Vehicles (FCV) fit best with these requirements. In the following this two technologies are compared concerning emissions, costs, range, system simplicity and infrastructure.

2 Comparison of Battery and Fuel Cell Electric Vehicles

In **Figure 1** different drive trains are classified starting with the conventional drive train on the left with increasing electrification going rightwards. A maximum of electrification is reached in the middle of the x-axes where the pure BEV is located. On the contrary in the left side the ICE is mechanically coupled to the drive train. In the right there is no mechanical connection of the ICE in the case it is used. The lower part of the graph shows the division of energy converters and on the upper part the corresponding energy carriers and storages respectively.

The electrification starts with hybridisation of the conventional drive train. Depending on the implemented electric performance different hybrid concepts such as micro-, mild- or full- are realised. In the middle of the sketch the pure BEV is located. Regarding the system complexity, like the conventional drive train the BEV combines only one energy carrier/storage with one energy converter. As it lacks a gearbox the BEV is even simpler. To extend the range of the pure BEV, the drive train is again supplemented with an ICE or a fuel cell. Because the ICE is mechanically decoupled from the drive train it is directly coupled to an electric generator, which converts the mechanical power output of the ICE into electrical power. On the very right of the sketch, the ICE/generator unit or the fuel cell has about the same maximum performance than the electric motor. The battery is then only needed as a buffer.

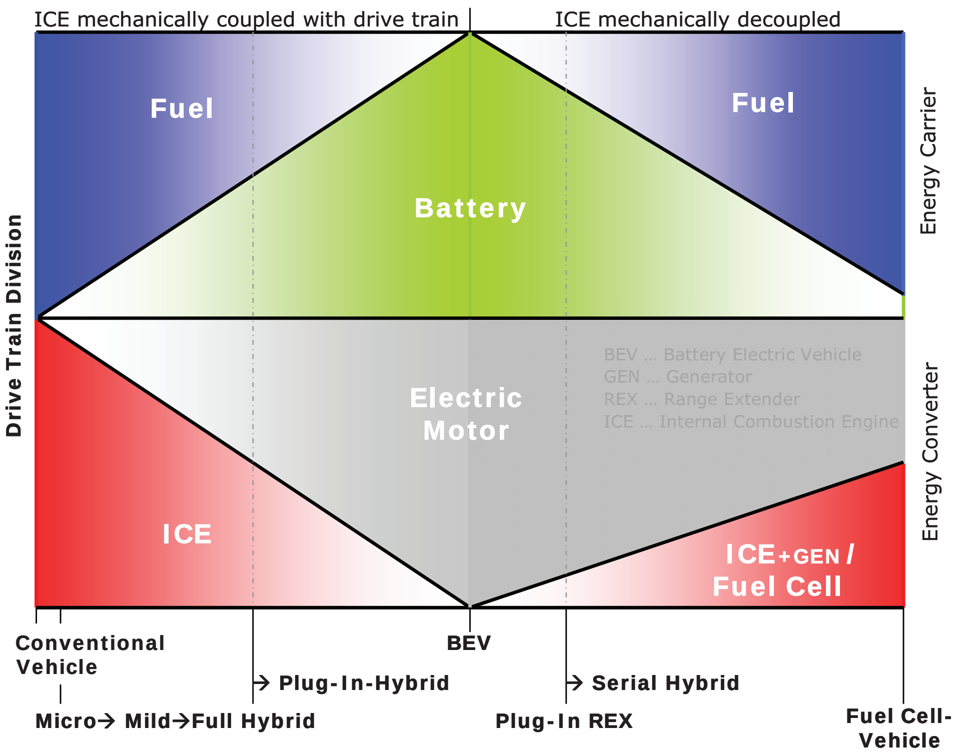

Figure 1: Drive train division from the conventional to the electric power train.

The wide range of vehicle classes and application areas require different technologies within and beyond electric vehicles (HEV, BEV, FCV). Especially in the case of long distance freight transport, other options like biofuels seem indispensable.

Hydrogen in fuel cells or internal combustion engines is an interesting option to increase vehicle range beyond battery vehicle limitations. Another asset of hydrogen is the broad choice of energy sources including renewable energies to generate hydrogen.

Limited driving range of BEV due to low energy density of batteries is sufficient in most cases of real driving behaviour. Figure 2 compares energy density of different battery technologies, hydrogen and conventional fuels. Hydrogen pressurized at 700 bar has a ten times higher energy density than a modern Li-Ion battery. Therefore a FCV reaches a significant higher range than a BEV, even though the efficiency of the battery electric drive train with 70 to 80 % is higher than the efficiency of the fuel cell drive train with 40 to 50 %.

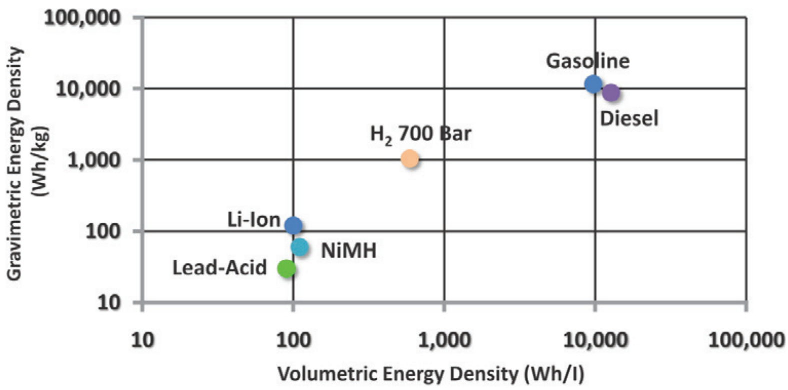

Figure 2: Energy density of different energy storages.

Figure 2 shows five critical factors for a successful market launch of both technologies. The clearest difference lies in the range. The fuel cell has there significant advantages in comparison to battery-electric drive trains because of the higher energy density of hydrogen. The present disadvantages of the FCV concerning higher overall system costs, a more complex system configuration as well as a higher effort to establish the hydrogen infrastructure must be reduced strongly during the next years to allow a necessary coexistence of both technologies. In the area of pollutant and noise emissions both technologies have equally high potential, as long as renewable energy is used for the production of hydrogen and the generation of electricity.

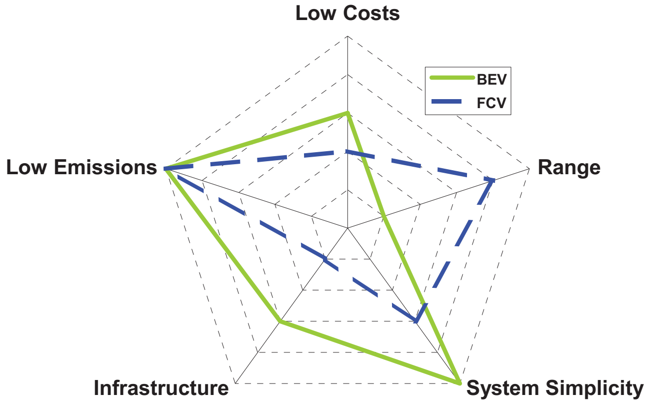

Figure 3: Key Factors of BEV and FCV.

3 Activities in the Field of Hydrogen in Austria

Graz, the capital of Styria, plays a particularly important role in the field of hydrogen research. HyCentA Research GmbH (Hydrogen Center Austria), which operates a hydrogen testing centre, the Institute for Internal Combustion Engines and Thermodynamics at the Graz University of Technology, the Joanneum Research Forschungsgesellschaft mbH and Magna Steyr Fahrzeugtechnik AG & Co KG form a hub for innovative hydrogen research and development.

Figure 4: Hydrogen Center Austria[1].

Located in northern Austria, Fronius International GmbH and Profactor GmbH are also actively involved in the field of hydrogen technology. The activities of OMV AG in Austria are supported by the company's participation through its subsidiaries in the German H_2 Mobility initiative.

4 Funding Programs and Instruments of the Austrian Federal Ministry of Transport, Innovation and Technology (BMVIT)

In order to secure the competitiveness of the Austrian automotive sector as well as to support it in the market introduction and implementation of cleaner technologies (especially in order to face the increasingly strict requirements regarding emissions and fuel economy set both by the EC and international agreements), the Austrian Ministry for Transport, Innovation and Technology (BMVIT) launched in the year 2002 the Program A3 (Advanced Austrian Automotive Technology). The complete portfolio of instruments of the BMVIT to support R&D activities and demonstration projects include:

- A3plus-Technology Program: cooperative R&D projects on alternative propulsion systems and fuels
- Program OptiDrive: ICE optimisation, light weight structures, electronics
- Lighthouse projects: demonstration for market introduction
- FFG basic program: bottom-up product optimisation
- Climate and Energy Fund: 500 Mio. € for climate protection
- Headquarter Program: supporting Austrian companies
- Infrastructure for research: e.g. HyCentA (Hydrogen Center Austria, conceived as an hydrogen test center and first hydrogen delivery station in Austria acts as a focal point and information platform for hydrogen-oriented research and development activities.
- Competence Centres (e.g. K2-Mobility for sustainable vehicle technologies)
- International Cooperation (7th EU-framework program, European Technology Platforms, ERA-NETs, IEA)
- Austrian Agency for Alternative Propulsion Systems (A3PS)

A3plus program and tender for lighthouse projects

In the A3plus program and its predecessor A3 hundred and fifty cooperative R&D projects for the development of alternative engines and fuels have been selected for funding in annual tenders for projects, on the basis of evaluation by international experts since 2002. Funds amounting to 43 Mio. € have been used for this purpose. Within the context of the "Technology Lighthouse Program for electric Mobility", which opened its first call in 2009, three project proposals with a requested funding volume of 22.5 Mio. € were submitted. In contrast to the A3plus projects, the lighthouse projects are demonstration projects devoted to optimize new technologies under real life conditions and to prepare the public for an impending technological shift. Several hydrogen projects from the A3plus technology program are described in the following sections.

5 Austrian Agency for Alternative Propulsion Systems and Fuels (A3PS)

Following the principles of modern technology policy, the BMVIT also provides non-financial support for Austrian industry and research institutions and has entered into a strategic public-private partnership within the Austrian Agency for Alternative Propulsion Systems (A3PS). A3PS was founded in 2006 and developed as a coordination platform and an international point of contact in the field of alternative engine systems and fuels. A3PS offers a broad range of services in support of its 26 member institutions in their joint efforts to develop alternative propulsion systems and to bring them on the market:

- Stimulating the cooperation among complementary partners, building up international research partnerships and interdisciplinary pilot and demonstration projects
- Providing, compiling and analyzing information (technology foresight and assessment, studies, lectures, workshops, conferences, travel reports,...).
- Supporting the creation of innovation friendly framework conditions (Regulatory- and fiscal policy, fuel taxation, endowment of research programs, 7. FP, codes and standards, emission limits, access to sensitive areas,...).
- International networking and marketing support for Austrian technological expertise and the engineering and product-know-how of its members through publications, presentations and the organization of conferences.

References

[1] HyCentA Research GmbH

Implementation of Hydrogen into the German Energy System

Dr. Johannes Töpler, German Hydrogen and Fuel Cells Association, DWV, Berlin, Germany
Reinhold Wurster, DWV and Ludwig-Bölkow-Systemtechnik, LBST, Munich, Germany

Abstract

The paper combines a study of German Hydrogen and Fuel Cell Association (DWV) with respect to the future energy situation with the perspectives of the use of renewable primary energies together with hydrogen as secondary energy carrier in Germany.

As a result of the study a reduction of fossil primary energy supply and increasing contributions by renewable energies within the next decades is to be expected. The potential of renewable energies to cover the energy demand is described as well as cost reductions of wind and photovoltaic energy in Germany and Europe. The increasing use of renewable vehicle fuels is investigated with special focus on hydrogen in short and long term considerations.

As a result the study will show an energy supply gap between decreasing fossil energies and increasing renewable energies which can only be bridged by a more efficient general use of energy.

As a result of an overall consideration of different secondary energies with respect to energy density, efficiency and environmental aspects, hydrogen has the best perspectives.

As an introduction strategy for the implementation of hydrogen in Germany a concentration of research and demonstration projects in a national program (NIP) is started and the industrial process for a market penetration of fuel cell vehicles with corresponding infrastructure is prepared by MoU's of the OEM's and related companies for building up of the infrastructure.

1 Introduction

Hydrogen as a universal energy carrier can be produced as secondary energy from a wide variety of primary energy sources. Considering the whole energy chain from production to end-use, hydrogen, used in fuel cells to power transport and stationary applications, can provide significant benefits in terms of greenhouse gas emissions and local pollutants through increased efficiency and/or lower rate of emission per end-use energy unit.

As the EU Strategic Energy Technology Plan is pointing out in its Technology Map[1] "The possible competition for primary energy sources for hydrogen production and other sectors of activities indicates a need for synergies and coordination between policies and industrial sector strategies". From today's observations, there also will be a mix of different solutions suited to individual mobility needs. This will include shifts in the modal split.

There is a broad consensus that the future powertrain is electric. Battery vehicles would be the most energy efficient solution. However, by evaluating different secondary energies (e.g. electricity, hydrogen) with respect to energy density, efficiency, environmental aspects and subject to customer performance expectations and infrastructure development (both electricity grid and hydrogen infrastructure), hydrogen in combination with fuel cell vehicles have excellent perspectives in the medium as well as in the long term.

2 Future Energy Supply

The aggregate supply of fossil and nuclear energy is expected to peak by around 2015.

After the peaking of the oil supply (today) [2], the global supply of natural gas and coal [3] is expected to reach a combined maximum by around 2020 – at the latest. This will have significant impacts on the total energy supply. With peak oil we are entering into a transition phase towards a post-fossil energy area.

The limitation in the availability of fossil energy resources as well as the threat of climate change to biosphere have led to the formulation of political goals with regard to security of energy supply and especially reduction of greenhouse gas emissions. All the underlying issues can be addressed in an efficient and sustainable way by energy conservation, by the increased use of renewable energy sources and by the use of hydrogen and fuel cells.

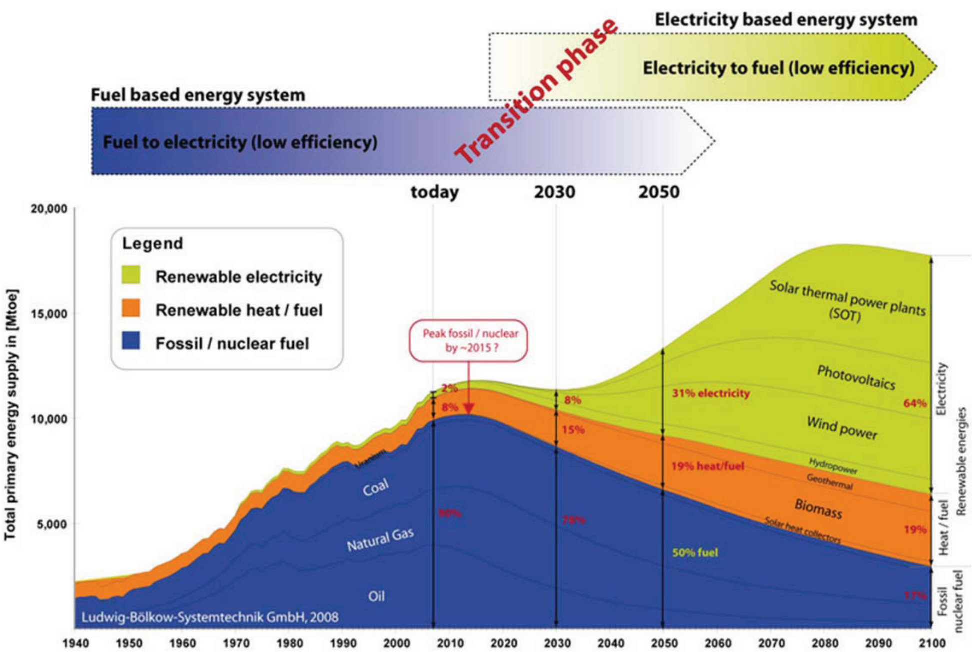

Figure 1: Future primary energy supply.

In the long term, renewable energies will be able to provide more energy than all fossil and nuclear fuels will have been able to supply at their aggregate peak. On a global level, solar energy and wind power can become the major pillars of our energy system.

The transition from fossil fuels to renewable energies is a transition from primary energy fuels (i.e. crude oil, natural gas, coal) to electricity (e.g. from photovoltaics, solarthermal power plants, wind or hydropower). This will offer new options and opportunities but also new challenges for the future energy system.

To a large extent, the transport sector will be electrified. Soon, road vehicles will start to switch to renewable electricity as a “primary energy source”. Hydrogen will become a very essential partner for the future transport sector. As electricity from wind and solar energy is difficult to store, hydrogen will serve as electricity storage and as a transport fuel for future vehicles. Vehicles with longer operating ranges, higher payloads and fast refuelling capabilities very likely will have to be hydrogen fuel cell vehicles in the foreseeable future.

3 First Markets – the Role of By-product Hydrogen

Today, large quantities of excess hydrogen are already available in some regions in Europe. In most cases hydrogen is produced as by-product in chemical processes. Hydrogen from these sources offers an interesting option for first applications in transport and stationary uses.

The major by-product producers in Europe are Germany (~850 m Nm^3/yr), Norway (~650 m Nm^3/yr), France (~300 m Nm^3/yr) and the Netherlands (~100 m Nm^3/yr)

In case hydrogen can be used near the production site, it can constitute an early but also economic source for first large-scale vehicle demonstrations and commercialisations. Also the use in efficient stationary fuel cell CHP units is feasible and economic.

As these sources are not available everywhere, they will have to be complemented by other hydrogen supply sources as time progresses. Nevertheless, these by-product sources can assist in providing low cost hydrogen efficiently, as they save the energetic losses and associated CO_2 emissions of at least 20% incurred by natural gas reforming or other conversion processes.

In order to give an estimate, if it is assumed that 850 million Nm^3 of by-product hydrogen can be made available as vehicular fuel in Germany, some 680,000 efficient fuel cell passenger cars could be operated [assuming an energy consumption of 0.3 kWh/vehicle-km and an annual operating range of 12,500 km/yr]. In a ramp-up strategy to ½ million FCVs towards 2020, these H_2 sources may well be sufficient until the end of the present decade.

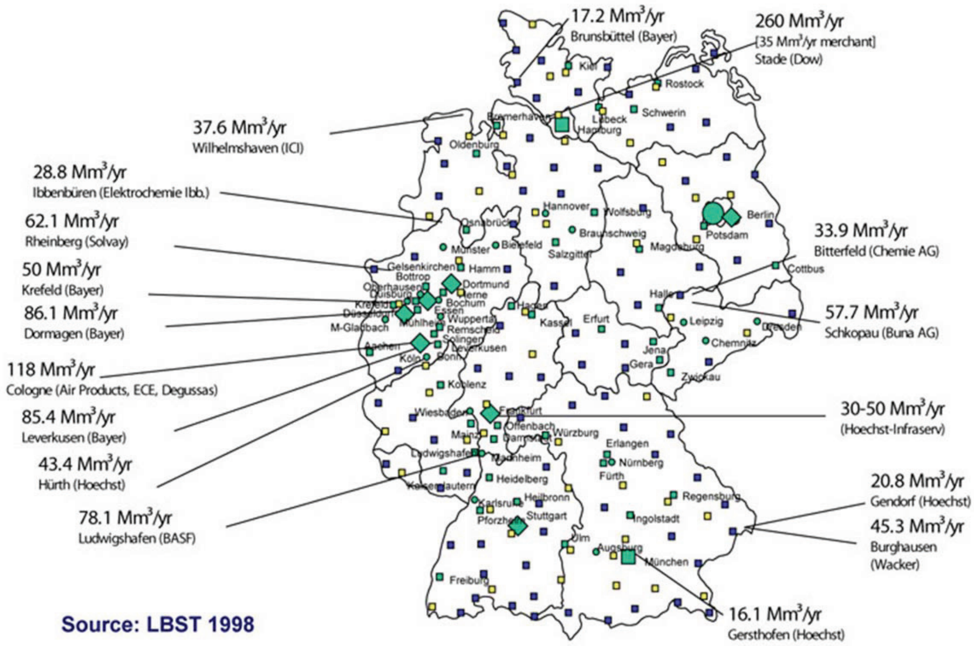

Figure 2: Potential for chemical by-product hydrogen in Germany.

In Germany, at various locations there is a surplus of hydrogen which today can only be burnt for thermal uses. This hydrogen, if substituted 1:1 by natural gas for its thermal uses, could be made available for other energetic uses with higher value, like e.g. vehicle fuel. In most cases purification and additional compression is required. In Germany the potential amounts to between 800 million and 1 billion Nm³/ year or 2.5-3 TWh (9-10.8 PJ).

4 Technical Potential of Renewable Energy

Renewable energy will become the most important energy of the world. [4]

For the EU the largest technical potentials for renewable electricity generation are identified for wind and solar energy. The technical potential in Europe 27 is estimated at 3,500 to 4,000 TWh/yr for wind energy and at 1500 to 2,000 TWh/yr for electricity from solarthermal power stations (SOT) and more than 1,000 TWh/yr for electricity from photovoltaic plants. In Germany the largest potentials are identified for wind and offshore and photovoltaics. (Figure 3)

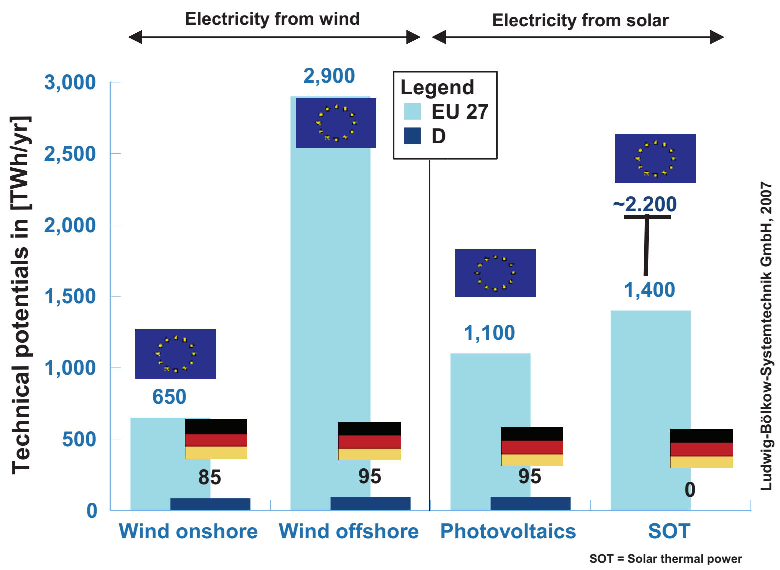

Figure 3: **Technical potential of wind and solar electricity in Europe and Germany.**

4.1 Biomass energy potentials

The potential of biomass for transport fuel production is limited and in direct competition with food production and other usages. The worldwide potential of solid biomass is estimated at about 95 EJ per year [5]. The EU potential lies in the order of 7-8 EJ per year.

Therefore it is not possible to substitute today's EU transport fuel consumption (approx. 15 EJ/ yr) or even a reduced demand of transportation fuel in the future completely by biomass from within the EU. A further increase of biofuel use requires the import of biofuels or biomass. But also on a worldwide level the potentials are limited and there are serious conflicts with the stationary sector for the energetic use of biomass and the food production chain worldwide.

As a result it can be concluded that biomass can only meet a relatively small fraction of the overall energy demand and only in some regions as negative environmental and social impacts should be avoided. The highest fraction of the future energy demand will be met by wind power and the direct use of solar energy.

5 Renewable Electricity Generation

The share of renewable electricity is expected to increase significantly since the largest potentials for renewable energies in Europe and Germany are identified as wind, hydropower, solar and geothermal electricity. In 2007, the German Federal Ministry for the

Environment, Nature Conservation and Nuclear Safety has published the Guiding Study 2007 "Development Strategy Renewable Energies"[6]. This study predicts that the electricity production from renewable resources will increase from 74 TWh in 2006 to 156 TWh in 2020. With regard to the current and presumably also the future electricity production this represents more than 25% of the overall production. This scenario also reflects the already enacted and binding goals of the European Union.

As can be seen in figure 4 the share of fluctuating and non-dispatchable renewable resources (onshore wind, offshore wind, solar) is increasing steadily reaching 59% of all renewable electricity in 2020 where offshore wind energy will be the main contributor to this growth. The proportion of this fluctuating and non-dispatchable resources will amount to 90 TWh in 2020, about 3 times the value of 2006.

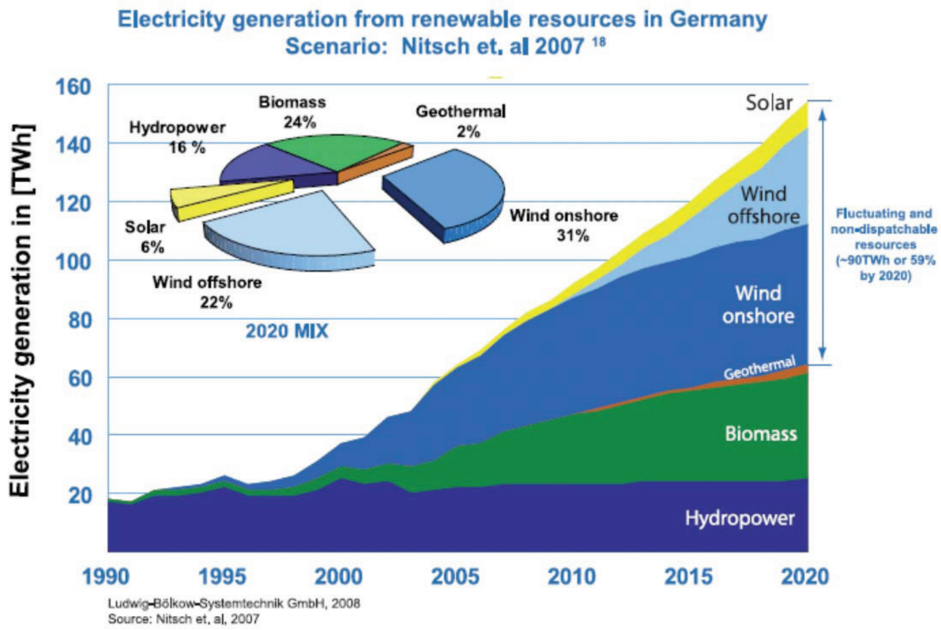

Figure 4: Scenario – renewable electricity in Germany until 2020.

5.1 Renewable electricity storage

With increasing share of renewable electricity our future energy system will require large scale storage systems for electricity. Today, pumped hydro power stations are the only widely used means to store electricity at industrial scale. But the potential for further extension and new installations is very limited. The only technology at present knowledge which has the potential for single storage systems in the 100 GWh range is the storage of hydrogen in underground salt caverns [7].

5.2 Hydrogen as storage for electricity

Hydrogen can be produced from electric power by high pressure electrolysers (≈ 3MPa). For efficient storage hydrogen has to be further compressed before stored in underground salt caverns at a pressure up to 30 MPa. For high power levels the most efficient conversion back to electricity can be achieved in combined cycle power plants. In the lower power range fuels cells can be applied. Round-trip efficiencies are expected to be in the range of 35- 40 %. The achievable storage capacity of compressed hydrogen is more than one order of magnitude higher than the one of compressed air. The storage of compressed hydrogen in salt caverns being relatively cheap, this technology qualifies especially for long-term storage of bulk energy to be reused during long-lasting unavailability of wind energy.

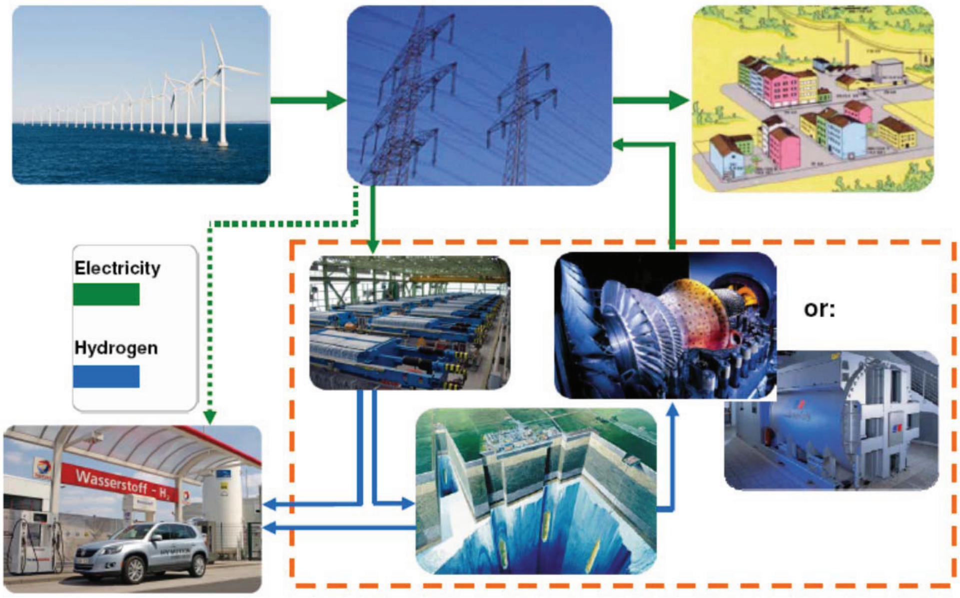

Figure 5: Ways of hydrogen storage.

5.3 Hydrogen as transport fuel

A further pathway for the utilisation of sustainably produced hydrogen will be its use in the transportation sector. The current discussions on CO_2 reduction and the availability of fossil fuels show, that car industry is speeding up with their efforts to develop hydrogen powered vehicles and that first significant vehicle sales can be expected around 2015 followed by a broad market entry towards 2020 (see Capter 6).

Furthermore, it can be observed that hydrogen propulsion in passenger cars is a twice as efficient end-use technology than today's direct injection engines and thus displaces conventional fuels and powertrains more efficiently than using hydrogen in stationary conversion units (combined cycle power plants or fuel cell systems) where it competes for the time being with almost as efficient natural gas-based end-use technologies.

Finally it should be mentioned, that these topics – large-scale storage of hydrogen, utilisation of hydrogen as a storage medium for electrical energy and the utilisation of surplus energy in the transportation sector – only played a sub-ordinate role in RD&D activities in the past.

5.4 Production costs of energies

Energy costs are expected to increase during the next decades due to the depletion of fossil and nuclear energy sources and rising investments in new power plants and infrastructure.

The graph in figure 6 shows rising costs for fossil energy sources and decreasing costs for renewable energies depending on the assumption that the break-even point between fossil and renewable electricity production will occur sometime between 2020 and 2030. Up to this date, the introduction of renewable energies will lead to higher average energy costs whereas after passing the break-even point, the growing contribution of renewable energy sources will reduce electricity costs compared to a purely fossil scenario.

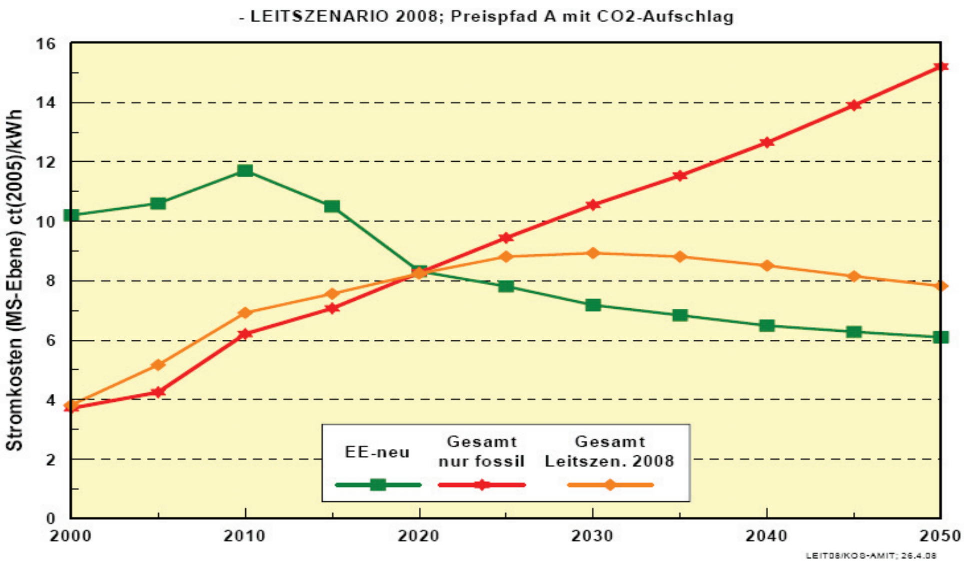

Figure 6: Average electricity cost scenario for renewable and fossil plants [8].

5.5 Infrastructure cost

For a fully functioning hydrogen road transport system in 2035, the HyWays project [www.hyways.de] assumed a scenario covering 6 European countries for which could be shown that more than 60% of the total investment costs have to be brought up for the conventional part of the vehicle.

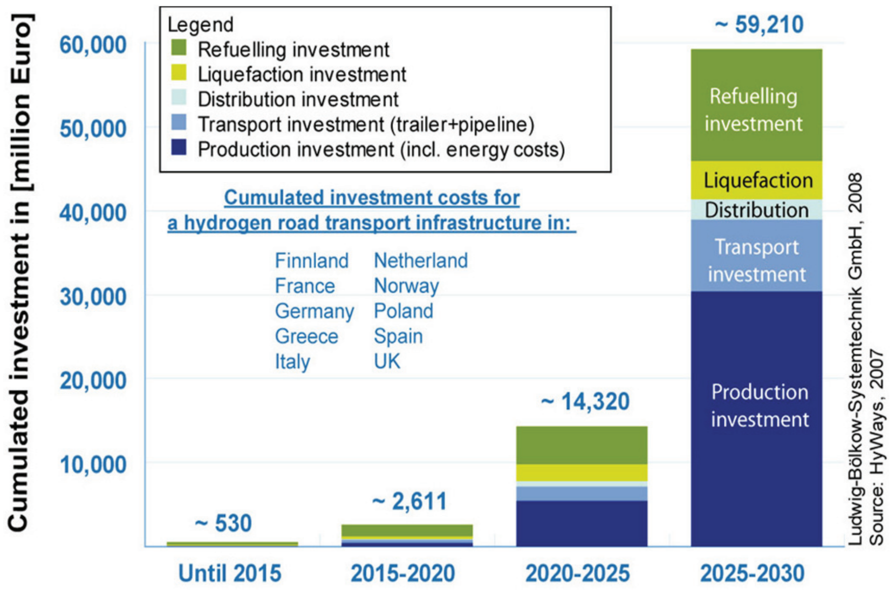

Figure 7: Cumulative investment costs for a hydrogen road transport system in six European countries.

Related to the total investment costs, the H_2 infrastructure part amounts to only 15-20 % of the total investment (i.e. H_2 production, transport, distribution and dispensing). About 60 % of the investment costs have to be brought up for the conventional part of the vehicle. The H_2-specific onboard part of the vehicle (e. g. FC and storage) amounts to about 20 % of the total investment costs.

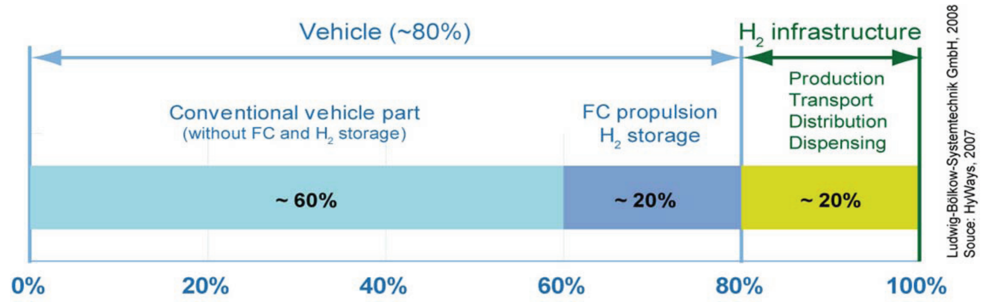

Figure 8: H_2 infrastructure versus H_2 vehicle investment.

Also hydrogen infrastructure costs are not the bottleneck for a fully functioning hydrogen road vehicle system in Europe.

6 Political Consequences and Perspectives

In recognition of the scientific and technical perspectives of the availabilities of renewable primary energies and hydrogen as secondary energy carrier different projects with significant support and financing by policy in Germany (incl. federal states) and Europe were initiated with respect to special topics of hydrogen applications [9].

One of the most important activities was the "Clean Energy Partnership (CEP) with the demonstration of hydrogen-fuelled vehicles with combustion engines and liquid hydrogen (BMW) as well as fuel cells and compressed hydrogen (DaimlerChrysler, VW, Opel, Ford) [10].

In the roadmap study "GermanHy" [11] a comparison of the political goals for the transport sector in Germany and the potentials of hydrogen was executed. (Figure 9)

with significant corresponces.

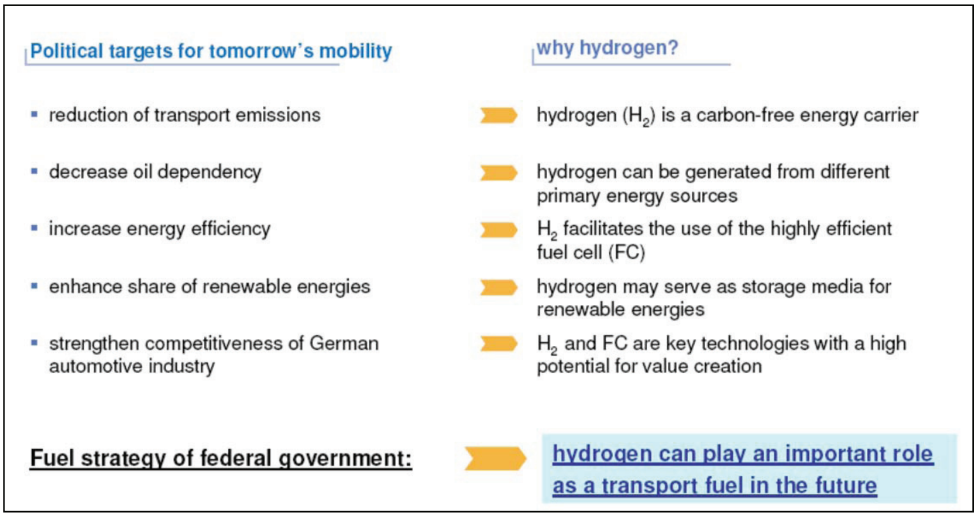

Figure 9: Comparison of political targets of transport sector in Germany and potentials of hydrogen in "GermanHy"[11].

Since 2008, all national activities in the field of hydrogen technology have been consolidated within the National Innovation Programme (NIP), which is administered by the "Nationale Organisation Wasserstoff" (National Hydrogen Organization, NOW). Under this programme, which is funded through equal contributions from the Federal Government and the industry totalling 1.4 billion EUR for a period of ten years, preparations are being made for the launch of hydrogen technologies in the market through research and demonstration projects. The programme focuses on both mobile applications (CEP II) and building energy supply (Callux) (Ill.) [11].

In cooperation of GermanHy and NIP the roadmap for hydrogen was elaborated. This includes a summary of perspectives of car numbers (passenger cars and trucks), H_2-demand and – cost, renewable energy sources and H_2-Infrastructure for the next 40 years as shown in figure 10.

In addition to this scientific study the realisation started in September 2009 by signing two Letters of Understanding by automotive and Infrastructure industry:

1) Daimler, Ford, GM/Opel, Honda, Hyundai, KIA Renault-Nissan and TOYOTA globally anticipate together "…that from 2015 onwards a quite significant number of fuel cell vehicles could be commercialised. This number is aimed at a few hundred thousand (100.000) units over life cycle on a worldwide basis."
2) Daimler, EnBW, Linde , NOW, OMV, Shell, Total and Vattenfall agree on a German build-up plan for hydrogen-infrastructure, flanking expected serial-production of FC-vehicles starting 2015 by standardization of hydrogen fuelling stations and a joint business plan for area-wide roll-out in Germany (Phase I, till 2011) and a implementation of respective action plan (Phase 2).

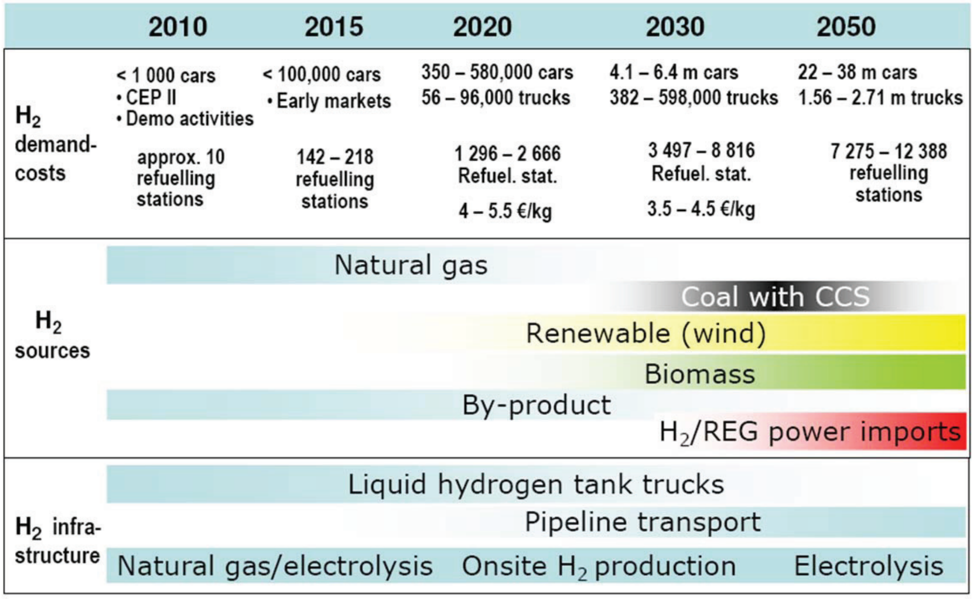

Figure 10: H2-Roadmap for Germany [11].

Additionally to the plans of mobile application the NIP-Programme includes lighthouse projects for fuel cells for domestic energy supply (Callux) and a project for stationary industrial energy supply (NEEDS).

For special markets first applications represent initial steps towards market penetration:

- fuel cell-applications in leisure and tourism markets (boat, light vehicles, caravans, etc.) and small utility and materials handling vehicles
- safe energy supply: public safety communication systems, uninterruptible power supply.

This paper has shown the important role hydrogen can play in a cleaner and more renewable energy and transport system in the future. It furthermore shows how renewable electricity can be phased into the energy system more successfully with hydrogen a crucially important long-term storage component and how the transport system will benefit from the largest potential of renewable energy, electricity, in a much wider scale than could be achieved with battery-electric vehicles only.

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