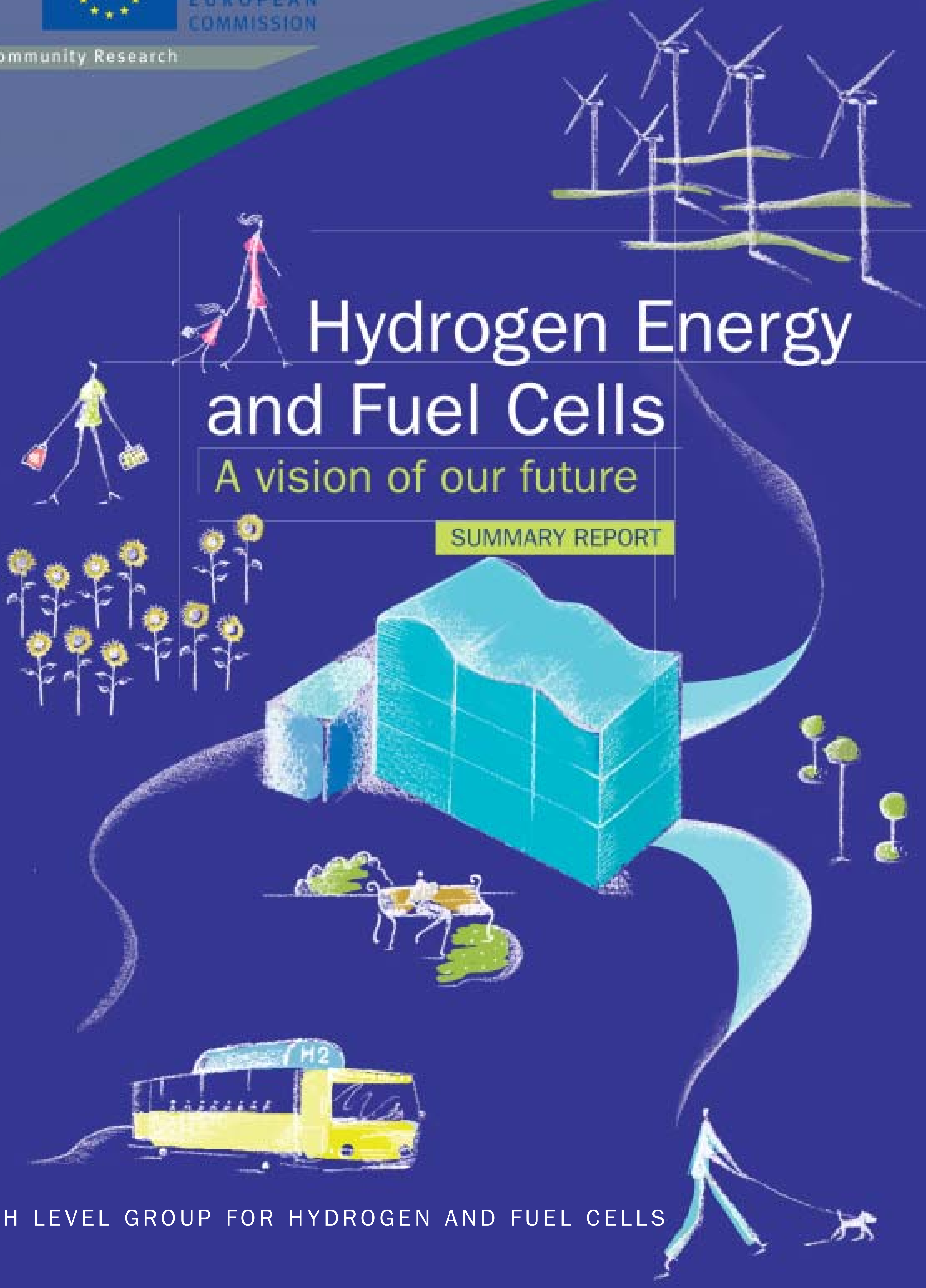
EUROPEAN COMMISSION

Community Research

Hydrogen Energy and Fuel Cells

A vision of our future

SUMMARY REPORT



HIGH LEVEL GROUP FOR HYDROGEN AND FUEL CELLS

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A VISION FOR OUR FUTURE

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Summary Report, June 2003

Background to this document

Hydrogen and fuel cells are seen by many as key solutions for the 21st century, enabling clean efficient production of power and heat from a range of primary energy sources. The High Level Group for Hydrogen and Fuel Cells was initiated in October 2002 by the Vice President of the European Commission, Loyola de Palacio, Commissioner for Energy and Transport, and Mr Philippe Busquin, Commissioner for Research. The group was invited to formulate a collective vision on the contribution that hydrogen and fuel cells could make to the realisation of sustainable energy systems in future.

This summary report has been produced as a communication to the conference "The hydrogen economy – A bridge to sustainable energy" to be held in Brussels on 16-17th June 2003. The terms of reference for the group requested the preparation of a vision report outlining the research, deployment and non-technical actions that would be necessary to move from today's fossil-based energy economy to a future sustainable hydrogen-oriented economy with fuel cell energy converters.

The High Level Group, whose members are listed in Annex I, comprises 19 stakeholders representing the research community, industry, public authorities and end-users. The Group was requested to give a stakeholder, not a company view. The report was compiled with the assistance of the High Level Group Members' "sherpas", and technical writers, who are listed in Annex II.

The report aims to capture a collective vision and agreed recommendations. Whilst members of the group subscribe to the collective view represented in the report, their personal view on detail aspects of the report may differ.

HIGH LEVEL GROUP FOR HYDROGEN AND FUEL CELLS

HYDROGEN ENERGY AND FUEL CELLS – A VISION FOR OUR FUTURE

The Energy Challenge

Worldwide demand for energy is growing at an alarming rate. The European "World Energy Technology and Climate Policy Outlook" (WETO) predicts an average growth rate of 1.8 % per annum for the period 2000-2030 for primary energy worldwide. The increased demand is being met largely by reserves of fossil fuel that emit both greenhouse gasses and other pollutants. Those reserves are diminishing and they will become increasingly expensive. Currently, the level of CO_2 emissions per capita for developing nations is 20% of that for the major industrial nations. As developing nations industrialise, this will increase substantially. By 2030 CO_2 emissions from developing nations could account for more than half the world CO_2 emissions. Industrialised countries should lead the development of new energy systems to offset this.

Energy security is a major issue. Fossil fuel, particularly crude oil, is confined to a few areas of the world and continuity of supply is governed by political, economic and ecological factors. These factors conspire to force volatile, often high fuel prices, while at the same time, environmental policy is demanding a reduction in greenhouse gasses and toxic emissions.

A coherent energy strategy is required, addressing both energy supply and demand, taking account of the whole energy lifecycle including fuel production, transmission and distribution, and energy conversion and the impact on energy equipment manufacturers and the end users of energy systems. In the short term, the aim should be to achieve higher energy efficiency and increased supply from European energy sources, in particular renewables. In the long term a hydrogen-based economy will have an impact on all these sectors. In view of technological developments, vehicle and component manufacturers, transport providers, the energy industry, and even householders are seriously looking at alternative energy sources and fuels and more efficient and cleaner technologies - especially hydrogen and hydrogen-powered fuel cells.

In this document, the High Level Group highlights the potential of hydrogen-based energy systems globally, and for Europe in particular, in the context of a broad energy and environment strategy. It then proposes research structures and actions needed for their development and market deployment.

Why hydrogen and fuel cells?

A sustainable high quality of life is the basic driver for providing a clean, safe, reliable and secure energy supply in Europe. To ensure a competitive economic environment, energy systems must meet the following society needs at affordable prices:

- *Mitigate the effects of climate change,*
- *Reduce toxic pollutants and*
- *Plan for diminishing reserves of oil.*

Failure to meet these needs will have significant negative impacts on

- *the economy,*
- *the environment and*
- *public health.*

Measures should therefore be introduced which promote:

- *more efficient use of energy and*
- *energy supply from a growing proportion of carbon free sources.*

The potential effects of climate change are very serious and most important of all, irreversible. Europe cannot afford to wait before taking remedial action, and it must aim for the ideal – an emissions-free future based on sustainable energy. Electricity and hydrogen together represent one of the most promising ways to achieve this, complemented by fuel cells, which provide very efficient energy conversion.

Hydrogen is not a primary energy source like coal and gas. It is an energy carrier. Initially it will be produced using existing energy systems based on different conventional primary energy carriers and sources. In the longer term renewable energy sources will become the most important source for the production of hydrogen. Regenerative hydrogen, and hydrogen produced from nuclear sources and fossil-based energy conversion systems with capture, and safe storage (sequestration) of CO_2 emissions, are almost completely carbon free energy pathways.

Producing hydrogen in the large quantities necessary for the transport and stationary power markets could become a barrier to progress beyond the initial demonstration phase. If cost and security of supply are dominant considerations, then coal gasification with CO_2 sequestration may be of interest for large parts of Europe. If the political will is to move to renewable energies, then bio-mass, solar, wind and ocean energy will be more or less viable according to regional geographic and climatic conditions. For example, concentrated solar thermal energy is a potentially affordable and secure option for large-scale hydrogen production, especially for Southern Europe. The wide range of options for sources, converters and applications shown in figures 1 and 2, though not exhaustive, illustrates the flexibility of hydrogen and fuel cell energy systems.

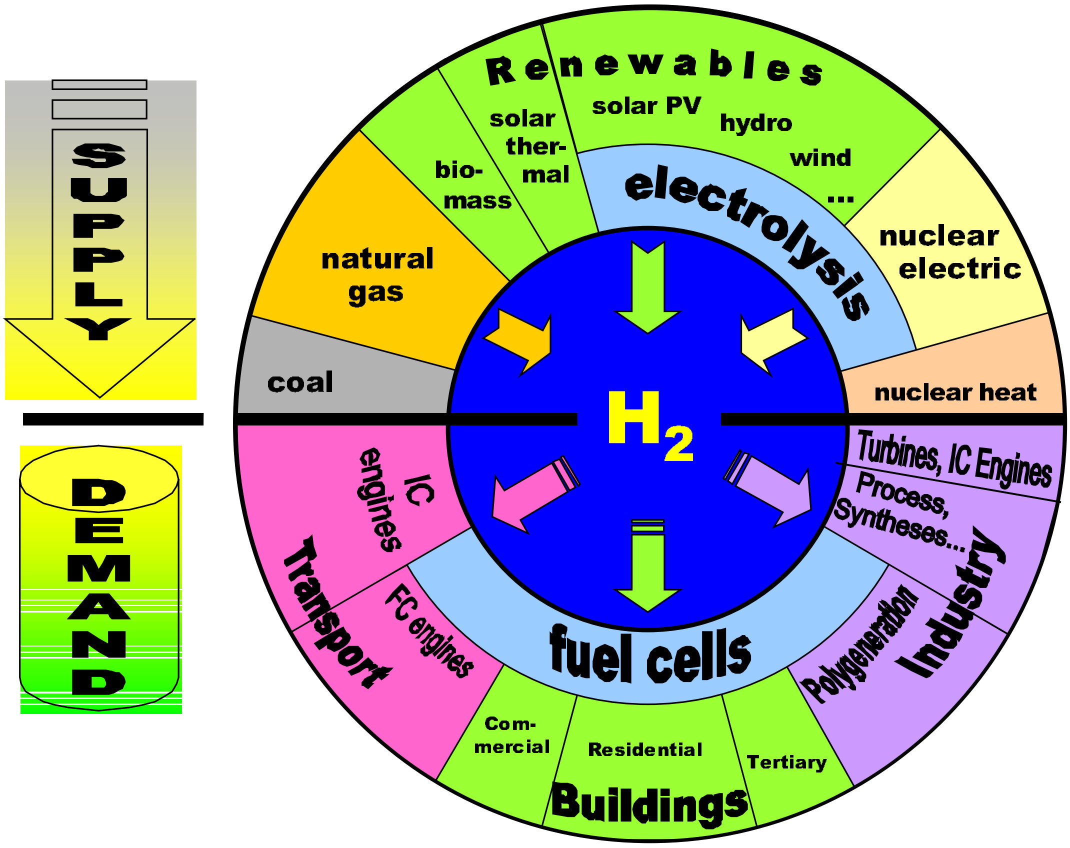

Figure 1: Hydrogen: primary energy sources, energy converters and applications
Note - Sizes of "sectors" have no connection with current or expected markets.

Fuel cells will be used in a wide range of products, ranging from very small fuel cells in portable devices such as mobile phones and laptops, through mobile applications like cars, delivery vehicles, buses and ships, to heat and power generators in stationary applications in the domestic and industrial sector. Future energy systems will also include improved conventional energy converters running on hydrogen (e.g. internal combustion engines, Stirling engines, turbines) as well as other energy carriers (e.g. direct heat and electricity from renewable energy, and bio-fuels for transport).

The benefits of hydrogen and fuel cells are wide ranging, but will not be fully apparent until they are in widespread use. With the use of hydrogen in fuel-cell systems there is very low to zero carbon emissions and no emissions of harmful ambient air substances like nitrogen dioxide, sulphur dioxide or carbon monoxide. Because of their low noise and high power quality, fuel cells systems are ideal for use in hospitals or IT-centres, or for mobile applications. They offer high efficiencies, which are independent of size. Fuel-cell electric drivetrains can provide a significant reduction in energy consumption, and regulated emissions. Fuel cells can also be used as Auxiliary Power Units (APU) in combination with internal combustion engines, or in stationary back-up systems when operated with reformers for on-board conversion of other fuels - saving energy and reducing air pollution, especially in urban congested traffic.

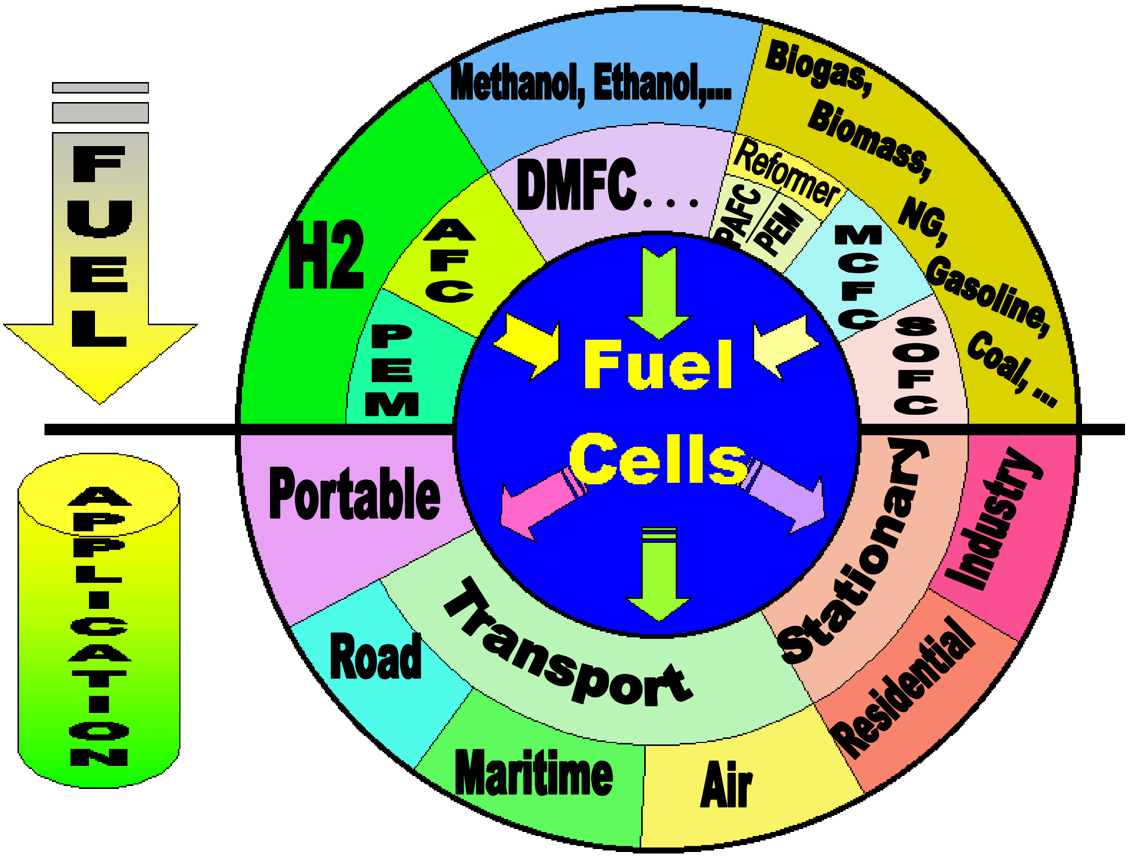

Figure 2: Fuel cell technologies, possible fuels and applications
Note - Sizes of "sectors" have no connection with current or expected markets.[1]

[1] **PEM** = Proton Exchange Membrane Fuel Cell ; **AFC** = Alkaline Fuel Cells ; **DMFC** = Direct Methanol Fuel Cell ; **PAFC** = Phosphoric Acid Fuel Cell ; **MCFC** = Molten Carbonate Fuel Cell ; **SOFC** = Solid Oxide Fuel Cell

In brief, hydrogen and electricity together represent one of the most promising ways to realise sustainable energy, whilst fuel cells provide the most efficient conversion device for converting hydrogen, and possibly other fuels, into electricity. Hydrogen and fuel cells open the way to integrated, “open energy systems” that simultaneously address all of the major energy and environmental challenges, and have the flexibility to adapt to the diverse and intermittent renewable energy sources that will be available in the Europe of 2030.

Europe should lead in undertaking rational analysis of alternative energy options and in demonstrating the benefits of a transition to a widespread use of hydrogen and fuel cells. They will have to provide cost-effective solutions to the following key challenges – the main drivers for Europe’s future energy systems.

Energy security and supply

Today’s society depends crucially on the uninterrupted availability of affordable fossil fuels, which in future will be increasingly concentrated in a smaller number of countries – creating the potential for geo-political and price instability. Hydrogen opens access to a broad range of primary energy sources, including fossil fuels, nuclear energy and increasingly renewable energy sources (e.g. wind, solar, ocean, and biomass), as they become more widely available. Thus the availability and price of hydrogen as a carrier should be more stable than any single energy source. The introduction of hydrogen as an energy carrier, alongside electricity, would enable Europe to exploit resources that are best adapted to regional circumstances.

Hydrogen and electricity also allow flexibility in balancing centralised and de-centralised power, based on managed, intelligent grids, and power for remote locations (e.g. island, and mountain sites). De-centralised power is attractive both to ensure power quality to meet specific customer needs, as well as reducing exposure to terrorist attack. The ability to store hydrogen more easily than electricity can help with load levelling and in balancing the intermittent nature of renewable energy sources. Hydrogen is also one of the few energy carriers that enables renewable energy sources to be introduced into transport systems.

Economic competitiveness

Since the first oil crisis in the 1970s, economic growth has not been directly linked with growth in energy demand in the industrial sector, whereas in the transport sector increased mobility still leads to a proportionate increase in energy consumption. The amount of energy needed per unit growth must be reduced and the development of energy carriers and technologies to ensure low cost energy supply is of great importance. Development and sales of energy systems are also a major component of wealth creation, from automobiles to complete power stations, creating substantial employment and export opportunities, especially to the industrialising nations. European leadership in hydrogen and fuel cells will play a key role in creating high quality employment opportunities, from strategic R&D to production and craftsmen.

In the US and Japan, hydrogen and fuel cells are considered to be core technologies for the 21st century, important for economic prosperity. There is strong investment and industrial activity in the hydrogen and fuel cell arena in these countries, driving the transition to hydrogen – independently of Europe. If Europe wants to compete and become a leading world player, it must intensify its efforts and create a favourable business development environment.

A strong drive in the United States and Japan

A coalition of US fuel cell stakeholders recently called for a 10-year US Federal Government Programme to implement and deploy hydrogen and fuel cell technologies. The coalition called for $5.5bn public funding. The US administration responded in January 2003 by proposing a total of $1.7 billion (including $720m new funding) over the next five years to develop hydrogen fuel cells, hydrogen infrastructure and advanced automotive technologies. According to the US Department of Energy those activities will result in 750.000 new jobs by 2030.

Japan is also aggressively pursuing research and demonstration of hydrogen and fuel cells with a 2002 budget estimated at around $240 m. The Japan Fuel Cell Commercialisation Conference managed by the Japanese Electric Vehicle Association will commission six hydrogen fuelling stations in Tokyo and Yokohama in 2002-3. The Japanese have announced initial commercialisation targets of 50.000 fuel cell vehicles by 2010, and 5m by 2020, and installed stationary fuel cell capacity of 2.100 MW by 2010, with 10.000MW by 2020.

Europe can only meet this global challenge with similar total levels of investment from individual states and the EU. The proposed US support is around five to six times the level of public support anticipated for hydrogen and fuel cells in the European Sixth Framework Programme for Research. Even with the significant additional support from individual member state programmes, the level of public support in Europe is still far below that in the United States. A substantial increase is therefore needed for Europe to compete with the USA and Japan. To be as effective, research, development and deployment would need to be well co-ordinated to achieve sufficient critical mass and avoid unnecessary duplication.

Air quality and health improvements

Improved technology and post combustion treatments for conventional technologies are continuously reducing pollutant emissions. Nevertheless, oxides of nitrogen and particulates continue to be a problem in certain areas, while the global trend towards urbanisation emphasises the need for clean energy solutions and improved public transport. Vehicles and stationary power generation fuelled by hydrogen emit zero emissions at the point of use, with consequential local air quality benefits.

Greenhouse gas reduction

Hydrogen can be produced from carbon free or carbon neutral energy sources or from fossil fuels with CO_2 capture and storage (sequestration). Thus the use of hydrogen could eventually eliminate greenhouse gas emissions from the energy sector. Fuel cells provide efficient and clean electricity generation from a range of fuels. They can also be sited close to the point of end-use, allowing exploitation of the heat generated in the process.

The table below illustrates how, in a mature hydrogen oriented economy, the introduction of zero carbon hydrogen-fuelled vehicles could reduce the average greenhouse gas emissions from the European passenger car fleet, compared to the average level of 140g/km CO_2[2] projected for 2008. The last column shows the corresponding amounts of CO_2 emissions that could be avoided. This may be compared to a projected total level of 750 - 800 Mt CO_2 emissions for road transport in 2010. The numbers for H_2 fuelled cars are an assumption based on a survey of experts for conventional and alternative automotive drive trains, but not a prediction of future production or sales.

[2] The European Automobile Manufacturers' Association (ACEA) has made a voluntary commitment to reduce the average level of CO_2 emissions to 140 g/km for new vehicles sold on the European market in 2008. The average level today is around 165-170 g/km.

YEAR	% of new cars[1] fuelled by zero-carbon hydrogen	% of fleet fuelled by zero-carbon hydrogen	Average CO_2-reduction (all cars)[2]	CO_2 avoided per year (Mt CO_2)
2020	5	2	2.8 g/km	15
2030	25	15	21.0 g/km	112
2040	35	32	44.8 g/km	240

[1] Figures based on an assumed European fleet of 175m vehicles. The fleet size will increase significantly by 2040, with correspondingly larger benefits.

[2] calculation is independent of total number of cars.

Greenhouse gas savings of about 140 $MtCO_2$ per year (14 % of today's levels of CO_2 emissions from electricity generation) could be achieved if about 17 % of electricity demand, currently supplied from mainly coal-based centralised power stations, is replaced by more efficient de-centralised power stations, incorporating stationary high temperature fuel-cell systems fuelled by natural gas. Fuel-cell systems will be used as base load in the future decentralised energy systems. Further savings are of course possible with CO_2 sequestration, although this may not be viable for smaller plants.

These examples *are not proposed as targets*, but merely to serve as illustrations of the CO_2 savings that could be achieved with quite modest penetrations of hydrogen vehicles and fuel cell-based stationary power generation. Together, 15% regenerative hydrogen vehicles and the above distributed fuel cell/gas turbine hybrid systems could deliver about 250 $MtCO_2$ savings per year. This is approximately 6 % of the energy related CO_2 emissions forecast in 2030 and progress such as this would allow Europe to move beyond the Kyoto protocol.

What can Europe do?

Europe has the skills, resources and potential to become a leading player in the supply and deployment of hydrogen technologies. Its diversity offers enormous strength if it can be harnessed and strategically guided, but European policy, research and development are presently fragmented both within and across the different countries.

Five actions to a hydrogen energy future

- *A Political Framework* that enables new technologies to gain market entry within the broader context of future transport and energy strategies and policies.

- A *Strategic Research Agenda*, at European level, guiding community and national programmes in a concerted way.

- A *Deployment Strategy* to move technology from the prototype stage through demonstration to commercialisation, by means of prestigious "lighthouse" projects, which would integrate stationary power and transport systems and form the backbone of a trans-European hydrogen infrastructure, enabling hydrogen vehicles to travel and refuel between Edinburgh and Athens, Lisbon and Helsinki.

- *A European Roadmap for hydrogen and fuel cells* which guides the transition to a hydrogen future, considering options, and setting targets and decision points for research, demonstration, investment and commercialisation.

- A *European Hydrogen and Fuel Cell Technology Partnership*, steered by an *Advisory Council*, to provide advice, stimulate initiatives and monitor progress – as a means to guide and implement the above, based on consensus between stakeholders.

The Political Framework

In view of the substantial long term public and private benefits arising from hydrogen and fuel cells, the European Union and national governments throughout Europe should work towards realising a consistent European policy framework with a sustainable energy policy at its heart. Ideally, any system should include the environmental cost of energy in the decision-making process. Policy developments must be long-term enough to provide comfort to industrial organisations and investors so that their investment risk can be managed. Leaders and champions are emerging from the private sector, but no single company, industry, or consortium can make transition happen. This is not only because of the significant investment required in research, development and deployment, and the associated risks. Additional obstacles include the need to reflect public benefit in individual commercial decisions, so that commercial activity can ultimately become the engine of transformation. Without the right pricing signals, the new “markets” will not develop given the existence of highly-developed, lower-cost (but less clean) alternatives in the existing energy and equipment mix.

Significant public sector involvement is critical to progress. Public sector funding is required to stimulate activity and share risks in research, development, and initial deployment. Public agencies are needed to provide mechanisms for co-ordinating activities efficiently, and to stimulate cross-business and cross-border co-operation. Fiscal and regulatory policies must be formulated which provide the commercial drivers for development, and these policies must be consistent with the stimulation of other parallel developments in clean energy/fuels. Co-ordination is required in the development of codes and standards, not only within regions but globally.

Co-ordinating policy measures

Ensuring that the take-up of hydrogen and fuel cells is rapid and widespread will mean co-ordination of strong policy measures in support of the technology, research and development, taking account of the time required for commercialisation. Such measures should address both supply and demand, taking into account global competitiveness, and reward technologies proportionate to their ability to meet policy objectives. They may include:

- Support (fiscal, financial and regulatory) for demonstration and pilot projects, through direct or indirect actions including fuel duty rebates and enhanced capital allowances
- Promotion of energy efficiency measures to stimulate demand for clean transport and stationary applications
- Support for infrastructure design, planning and assessment of viability, at the various stages of market development
- Review and remove regulatory barriers to commercialisation of hydrogen and fuel cells
- Review and develop codes and standards to support commercial development
- Simplification and harmonisation of planning and certification requirements (e.g. fuel and safety standards)
- Assessment of the scope and effectiveness of alternative mixes of policy measures, including market pull/incremental pricing policies and active use of public procurement schemes, including possible defence applications
- International co-ordination of policy development and deployment strategies

The Strategic Research Agenda

First class research is critical to the development of competitive, world-class technology. A Strategic Research Agenda should bring together the best research groups in Europe today. It should generate a critical mass in terms of resources, effort and competencies to analyse and address non-technical and socio-economic issues, and solve the remaining technical barriers to the introduction of hydrogen and fuel cells, including:

- Solving the technology challenges of hydrogen production, distribution, storage, infrastructure and safety, and reducing the costs of all of these as well as the improvement of the materials, components and system design;
- Solving the technology challenges of fuel cell stack performance, durability and costs, as well as of all the peripheral components (reformer, gas cleaning, control valves, sensors, air and water management systems);
- Executing systems analyses providing scenarios, techno-economic, environmental and socio-economic analyses of different energy carrier/converter configurations and transition pathways, including the range of hydrogen production to end-use routes and the range of fuel cells applications, to assess the viability of different options;
- Contributing to the definition, ongoing review and refinement of a European Hydrogen Roadmap with targets, milestones and review criteria based on research results.

The Strategic Research Agenda should identify in detail priorities for focused fundamental research where basic materials research, or in-depth modelling studies as well as applied research are required to achieve technical breakthroughs.

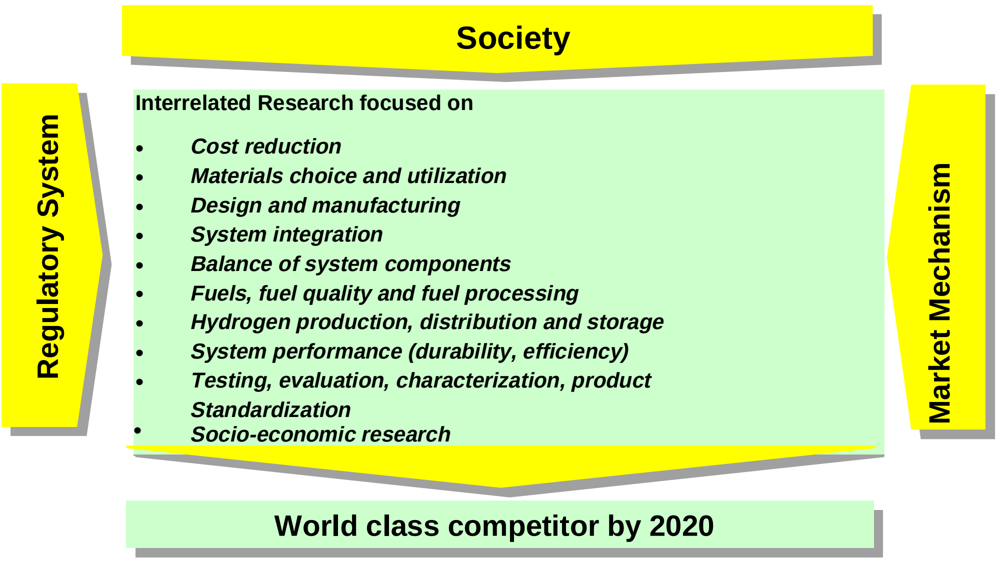

Figure 3: Key elements and drivers of a Strategic Research Agenda

The Strategic Research Agenda should define short, medium and long-term actions in a seamless way. Synergies between fuel pathways, infrastructure, and different fuel cell applications should be identified early on. The goal should be modular solutions and systems integration, facilitated by ambitious demonstration projects.

Implementing the research agenda

The Strategic Research Agenda should seek support from various public and private sources, including national and regional research programmes and the European Framework Programme for Research. It should build on ongoing European agreements, initiatives, projects, and thematic networks which have a strategic dimension. Specific implementation measures should include:

- Designation of a number of strategic European virtual centres of excellence acting as focal points for critical research.
- Establishment of a number of prototype demonstration projects to validate technology.
- Definition of rules on intellectual property leading to co-operative international research.
- Encouragement and facilitation of international co-operation, especially where it can accelerate market development.
- Establishment of stakeholder forums and a Strategic Research Agenda steering committee

- Investigation of mechanisms for developing joint research programmes between member states, including the use of article 169
- Co-ordination of research and development for defence applications;
- Reviewing criteria, targets and milestones of the European Roadmap for Hydrogen and Fuel Cells.

Setting the Strategic Research Agenda therefore requires co-operation between a broad range of stakeholders including academe, national, defence and contract (private) research centres, industry, end-users, civil society, Small and Medium Enterprises and public authorities at all levels – local, regional and European. It should also address broader international targets to ensure European technology will be internationally competitive.

A Deployment Strategy for Hydrogen and Fuel Cells

At present, hydrogen and fuel cells do not offer sufficient short-term end-user benefits to justify their higher costs compared to conventional technologies. The deployment strategy should therefore aim to identify pathways for increasing infrastructure and production volumes. This approach will reduce costs, create market opportunities, eventually reducing the need for government support. In certain applications such as portable power, emergency back-up power, auxiliary power units, fuel cells may offer early customer benefits and attract premium prices. However, for the emerging stationary and transport markets government intervention will be necessary, anticipating public and private benefits in the longer term.

Implementing the transition to hydrogen and fuel cells

Moving from the fossil fuel economy of 2003 to a hydrogen and fuel cell-based economy will not happen immediately. Large physical and economic infrastructures support the status quo. Switching too quickly could cause major economic dislocation. A strategy is required to maximise the benefits of transition technologies such as combustion engines, and to explore on-board reforming options to enable fuel cell vehicles to use existing fuel infrastructures.

Stationary fuel cells are already emerging in specific market niches. Fuel cell vehicle drive-trains are still at the pre-commercial development stage. Fuel cells in the stationary market will largely operate on natural gas until hydrogen becomes widely available (it may also be distributed through mixing with natural gas). Fuel cells will also be introduced into portable applications and stand-alone electricity generation, possibly using energy carriers such as bio-fuels or synthetic fuels. Early uses in vehicles may include auxiliary power units for on-board electricity generation, e.g. for refrigerated trucks, air-conditioning units for buses, and luxury cars. Development of fuel cells for defence applications as strategic niche markets could significantly speed development for civilian fuel cells. During the transition phase and even afterwards, conventional technologies will be essential. Hydrogen fuelled internal combustion engines and turbines can be used for stationary power and transport. Fuel cell vehicles will have to compete with very clean, efficient hybrid combustion engine/electric vehicles, although commercialisation of hybrid drivetrains will reduce the costs of electrical and electronic components shared with fuel cell vehicles.

For transport, a widespread refuelling infrastructure is essential for customer acceptance. Very large capital investments are required for a dedicated hydrogen infrastructure, in the order of some hundreds of billions of Euros. This is a major barrier to commercialisation. Hydrogen fuelling stations can be erected, using locally or industrially produced hydrogen. The existing hydrogen pipeline network in Europe (some 1100km) which has served industry for many years could be developed for initial demonstrations. Liquid hydrogen is also routinely distributed by truck and existing capacity could be readily developed to cope with up to 5% of new vehicles. Hydrogen may also be mixed with natural gas and distributed in natural gas pipelines. On-board reforming technologies, which take advantage of current infrastructure, should be investigated in parallel to the development of viable hydrogen storage and refuelling technologies.

The introduction of hydrogen vehicles is expected to start with centrally operated fleets of buses and city goods delivery vehicles in densely settled mega-cities, followed by private cars. Urban buses are attractive due to the centralised re-fuelling facilities, the availability of skilled personnel, the engineering tradition of public transport companies, the intensive service schedule under arduous, congested conditions, and for promotion of public awareness. A trans-European Hydrogen energy network can then be progressively grown from these strategically sited nucleii.

Maritime applications from canal barges to ocean-going vessels will provide opportunities for hydrogen and fuel cells. Successful introduction of fuel cells – and hydrogen – into transport, will involve considerable initial support from governments and industry. The development of improved codes and standards and the establishment of "best practice" for fuel-station lay-outs, preferably co-ordinated internationally, should lead to significant reductions in licensing times and costs. And of course, initial demonstration projects should promote public acceptance, and demonstrate that hydrogen is safe.

Stationary hydrogen combustion and fuel cell systems should be demonstrated in areas where they offer early benefits such as remote areas, island communities with renewable resources and micro-grids with combined heat and power. Actually linking together stationary and transport demonstrations will help to get the most from the technology and improve understanding of the probable synergies. Support should be given not only to large companies but also to small entrepreneurial companies seeking to establish niches.

Extensive demonstrations and field trials are critical to commercialisation. They are necessary to demonstrate the benefits, reliability and durability to potential users and governments.

Funding the transition

The investment required for building a hydrogen and fuel cell energy economy is estimated at some hundreds of billions of euros, which can only be realised over decades, as existing capital investments are depreciated. For example, installing hydrogen at 30% of Europe's fuel stations (penetration needed for customer comfort) could cost in the order of 100-200 billion euros. Public funding is very important, symbolising government commitment to the technology and generating leverage for private finance, the main engine of change. The Framework Programme and national programmes will remain the main public-funding instruments for research, development and demonstration, while regional aid projects could provide opportunities for larger deployment initiatives. For ambitious projects co-financing from several sources should be explored.

A European roadmap for hydrogen and fuel cells

Moving Europe away from its 20th century dependency on fossil fuels to an era powered by the complementary energy carriers, electricity and hydrogen, will require careful strategic planning. Hydrogen is not likely to be the only fuel for transport in future. Moreover, maintaining economic prosperity during the transition period will involve maximising efficient use of various forms of fossil-based energy carriers and fuels such as natural gas, methanol, coal and synthetic liquid fuels derived from natural gas. During that time it will also be important to introduce renewable energy sources such as bio-mass, organic material mainly produced by the agriculture and forestry sectors that can be used to generate heat, electricity and a range of fuels, like synthetic liquid fuels and hydrogen. Where appropriate, traditional forms of electricity generation can be harnessed to produce hydrogen through the electrolysis of water, while employing new, safe technologies and renewable sources to minimise harmful emissions of greenhouse gasses and pollutants. Throughout the period, electricity from renewable energy sources can be increasingly used to generate hydrogen. The ability to store hydrogen more easily than electricity opens up interesting possibilities for storing energy, helping to level the peaks and troughs experienced in the electricity generating industry. Hydrogen fuelling stations can be erected, using locally or industrially produced hydrogen. Given the complex range of options, a framework for the introduction of hydrogen and fuel cells needs to be established. This transition should be executed progressively along the following broad lines:

In the short and medium term (to 2010):

- Intensify the use of renewable energy sources for electricity which can be used to produce hydrogen by electrolysis or fed directly into electricity supply grids.
- Improve the efficiency of fossil-based technologies and the quality of fossil-based liquid fuels.
- Increase the use of synthetic liquid fuels produced from natural gas and biomass, which can be used in both conventional combustion systems and fuel-cell systems.
- Introduce early applications for hydrogen and fuel cells in premium niche markets, stimulating the market, public acceptance and experience through demonstration, and taking advantage of existing hydrogen pipeline systems.
- Develop hydrogen-fuelled IC engines for stationary and transport applications, supporting the early deployment of a hydrogen infrastructure, provided they do not increase the overall CO_2 burden;

Considerable fundamental research is needed throughout this period, on key technology bottlenecks, e.g. hydrogen production, storage and safety, and fuel cell performance costs and durability.

In the medium term (to 2020):

- Continue increasing the use of liquid fuels from biomass.
- Continue using fossil based liquid and gaseous fuels in fuel cells directly and reforming fossil fuels (including coal) to extract hydrogen. This enables transition to a hydrogen economy, capturing and sequestering the CO_2. The hydrogen thus produced can then be used in suitably modified conventional combustion systems, hydrogen turbines and fuel-cell systems, reducing greenhouse gas and pollutant emissions.
- Develop and implement systems for hydrogen production from renewable electricity, biomass; continue research and development for other carbon-free sources, such as solar thermal and advanced nuclear.

In the medium to long term (beyond 2020):

- Demand for electricity will continue to grow, and hydrogen will complement it. Use both electricity and hydrogen together as energy carriers to progressively replace the carbon-based energy carriers by the introduction of renewable energy sources and improved nuclear energy. Expand hydrogen distribution networks. Maintain other environmentally benign options for fuels.

A very preliminary, skeleton proposal for the main elements and timelines of a European roadmap for the production and distribution of hydrogen, as well as fuel cells and hydrogen systems, is presented in Figure 4 as a basis for wider consultation and discussion.

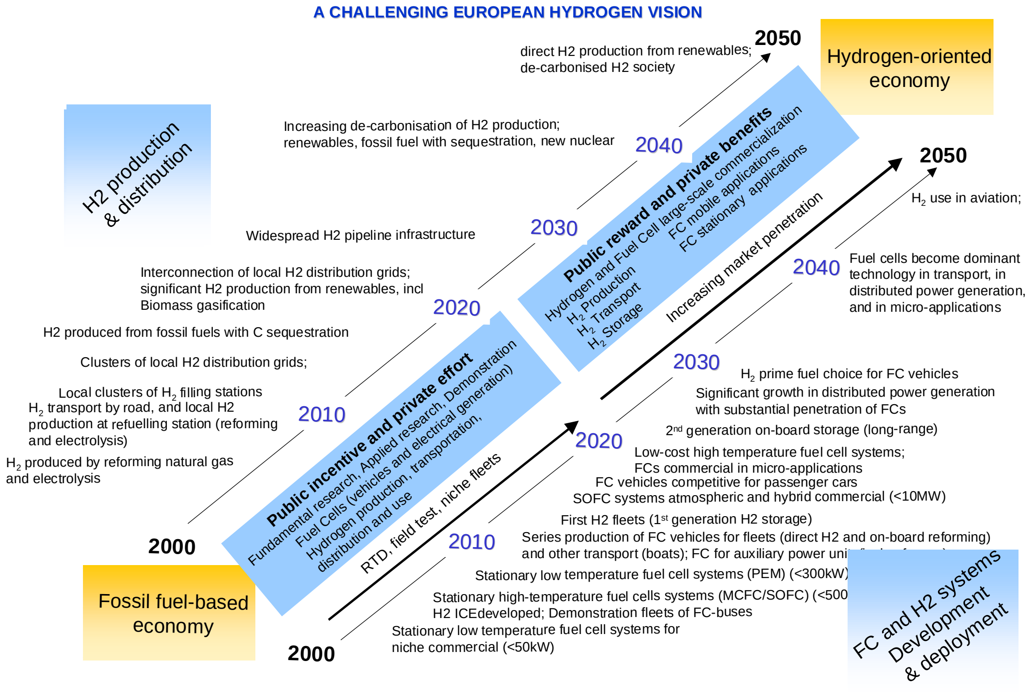

Figure 4: Skeleton proposal for European hydrogen and fuel cell roadmap

The European Hydrogen and Fuel Cell Technology Partnership

It is recommended that, to stimulate and manage the above initiatives, a European Hydrogen and Fuel Cell Technology Partnership should be formed without delay. The partnership should include the most important and innovative companies working on hydrogen and fuel cells in Europe and also represent a balance of expert knowledge and stakeholder interests. It should be steered and monitored by an Advisory Council, which should provide guidance on how to initiate and push forward the individual elements above, building on existing European initiatives, networks and structures. The High Level Group is ready and willing to offer advice on the implementation of the partnership and assist with the next steps. Specific 'initiative groups' should be created, including for example: strategic technical and socio-economic research; hydrogen policy; business development; demonstration; education and training; safety and standards, etc.. A business framework should be developed as soon as possible, to support the development of a component supply chain and stimulate innovation. The partnership should:

- Set clear objectives and commercialisation targets, foster strategic planning and deployment in response to policy priorities and monitor progress;
- Launch a business development initiative to foster investment in innovation, involving venture capital companies, institutional investors, regional development initiatives, and the European Investment Bank ;
- Promote an education and training programme, through the development of a master-plan for education and information, to stimulate learning at all levels ;
- Introduce a strategy for building international co-operation with both developed and developing countries with a view to co-operating on technology bottlenecks, codes and standards, and technology transfer ;
- Establish a centre for consolidating and disseminating information that could significantly aid co-ordination of a shift towards hydrogen and fuel cells.

Summary Conclusions and Recommendations

To maintain economic prosperity and quality of life, Europe requires a sustainable energy system that meets the conflicting demands for increased supply, increased energy security, whilst maintaining cost–competitiveness, reducing climate change and improving air quality.

Hydrogen and fuel cells are firmly established as strategic technologies to meet these objectives. They can create win-win situations for public and private stakeholders alike. The benefits will only start to really flow after public incentives and private effort is applied to stimulate and develop the main markets - stationary power and transport. This should be done in a balanced way that reflects the most cost-effective use of the various alternative primary energy sources and energy carriers.

Competition from North America and Pacific Rim countries is especially strong, and Europe must substantially increase its efforts and budgets to build and deploy a competitive hydrogen technology and fuel cell industry. This should not be left to develop in an uncoordinated fashion, at the level of individual member states. Gaining global leadership will require a coherent European-level strategy, encompassing research and development, demonstration, and market entry similar to the development of the European aircraft industry.

The High Level Group therefore recommends the formation of a **Hydrogen and Fuel Cell Technology Partnership**, steered by a **European Hydrogen and Fuel Cell Advisory Council** to provide advice, stimulate initiatives and monitor progress**.** The Advisory Council will provide governance and input from the different stakeholders in the hydrogen energy arena, and oversee the establishment of specific 'initiative' groups, to take forward the development of a broad and far-reaching hydrogen and fuel cell programme, comprising:

- Creation of **a policy framework that is coherent across transport, energy, and environment** to reward technologies that meet policy objectives
- A **substantially increased technical research and development budget** in hydrogen and fuel cell technologies, from fundamental science to validation programmes
- A **demonstration and pilot programme** to extend the technology validation exercises into the market development arena, through a number of "lighthouse" demonstration projects
- An **integrated socio-economic research programme** to complement and steer the technical support
- A **business development initiative**, bringing together different financing organisations to provide leadership for technology exploitation
- A **Europe-wide education and training programme**, spanning primary schooling to world-class research
- **Enhanced international co-operation**, working in partnership with North America and the Pacific Rim, as well as the developing world, to speed up the introduction of sustainable energy technologies
- **A communication and dissemination centre** for all these initiatives.

Detailed planning and actions for

implementing these recommendations

needs to start now,

with a twenty to thirty year perspective.

ANNEX I

HIGH LEVEL GROUP ON HYDROGEN AND FUEL CELLS TECHNOLOGIES

Company	Person	Position
Air Liquide	Daniel Deloche	Vice-President Space and Advance Technical Division
Ballard Power Systems	André Martin	Managing Director Europe and Transportation Programs
CEA	Alain Bugat	Chairman
CIEMAT	César Dopazo	General Director
Daimler-Chrysler	Herbert Kohler	Vice President for Research Body and Powertrain, Chief Environmental Officer
ENEA	Carlo Rubbia	President
FZJulich	Gerd Eisenbeiß	Member of The Board of Directors
Iceland	Hjalmar Arnason	Member of Parliament of Iceland
Johnson Matthey	N.A.P. Carson	Executive Director
Norsk Hydro	Tore Torvund	Executive Vice President of Norsk Hydro and CEO of Norsk Hydro Oil and energy
Nuvera	Roberto Cordaro	President and Chief Executive Officer
Renault	Pierre Beuzit	Vice-president of Research, Renault SA
Rolls-Royce	Charles Coltman	Chairman and CEO Rolls-Royce Fuel Cell Systems Ltd
Shell	Jeremy Bentham	Chief Executive Officer of Shell Hydrogen
Siemens-Westinghouse	Thomas Voigt	President Stationary Fuel Cell Division
Solvay	Leopold Demiddeleer	Solvay Corporate R&D Director
Sydkraft	Lars Sjunnesson	Director of Corporate R&D and Environment
UITP	Wolfgang Meyer	President
Vandenborre Technologies	Hugo Vandenborre	President and Chief Executive Officer

ANNEX II

HIGH LEVEL GROUP ON HYDROGEN AND FUEL CELLS TECHNOLOGIES: SHERPAS

Company	Person	Position
Air Liquide	Philippe Paulmier	Marketing Manager
Ballard Power Systems	Arnold Vanzyl	Research Delegate
CEA	Paul Lucchese	Hydrogen & Fuel Cells Project Manager
CIEMAT	Pedro Garcia Ybarra	Subdirector General
Daimler-Chrysler	Andreas Docter / Jörg Wind	Project Manager Fuel Cells
ENEA	Raffaele Vellone	Head Project
FZ JULICH	Bernd Hoehlein	Deputy Head of Institute for materials and processes in energy systems
Iceland	Jon Bjorn Skulason	General Manager
Johnson Matthey	Ian Stephenson	Executive Director Environment
Norsk Hydro	Ivar Hexeberg	Vice-President and leader of the Hydrogen Business Unit in Hydro Energy
Nuvera	Alessandro Delfrate	Sales Manager
Renault	Christophe Garnier	Head of Department Energy Systems
Rolls-Royce	Olivier Tarnowski	Principal Technologist
Shell	Chris de Koning	External Affairs & Communication Manager
Siemens	Klaus Willnow	Key Account Manager, Energy Policy
Solvay	Guy Laurent	Programme Manager
Sydkraft	Bengt Ridell	Consultant
UITP	Laurent Dauby	Manager Programmes and Studies
Vandenborre Technologies	Christian Machens	Co-ordinator European Programme

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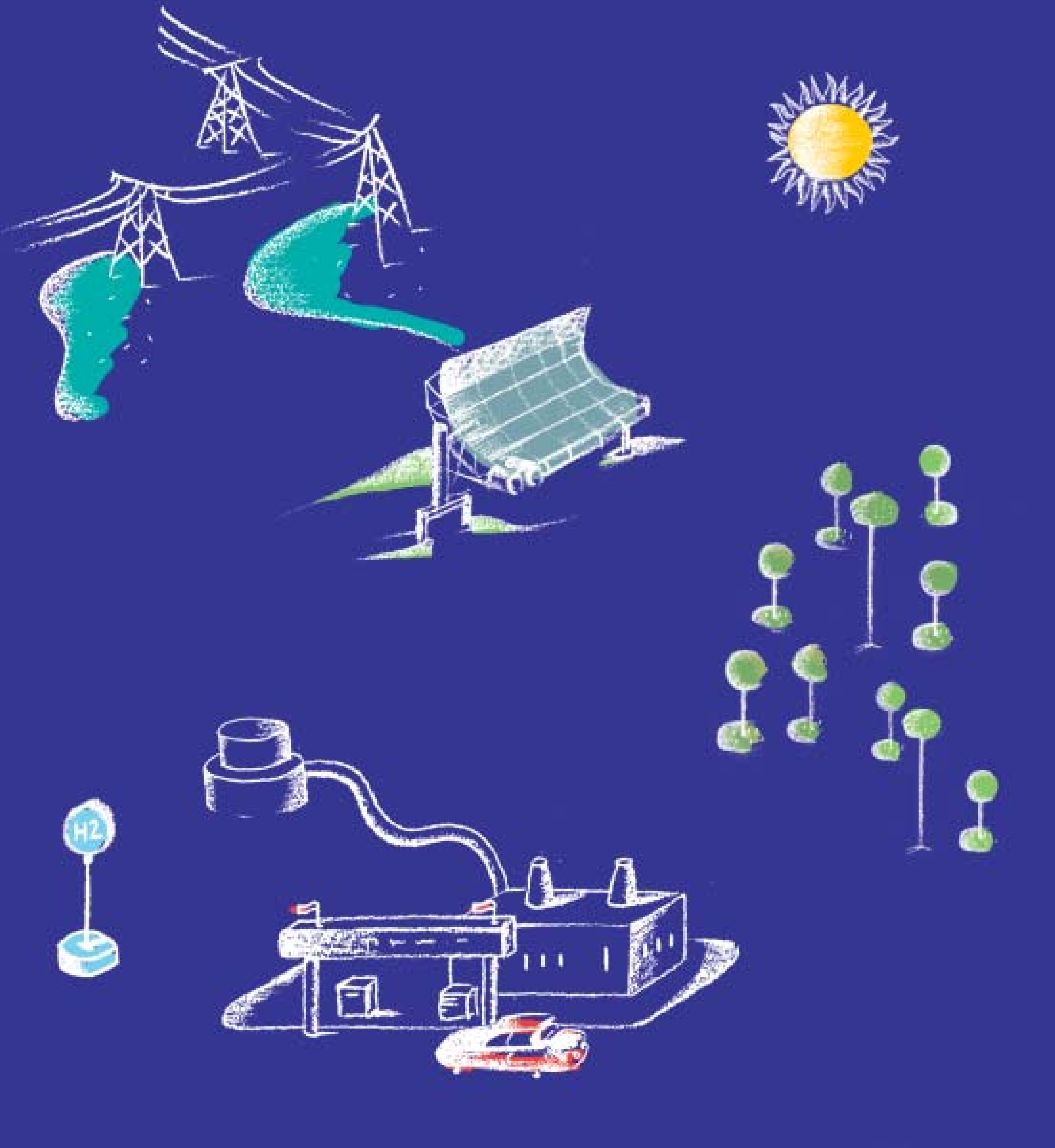
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