

A Vision of the Hydrogen Economy in Wales

Placing Wales in a position to take full advantage of the hydrogen economy

Executive Summary

The vision for a hydrogen economy in Wales presented here has been produced following a thorough consultation exercise with over 100 key stakeholders in the future hydrogen economy in Wales. Central to this process were two seminars held in March and June 2004 and organised by the WDA led Hydrogen Valley Initiative and the University of Glamorgan's Hydrogen Research Unit. These seminars helped to identify the important aspects of a future hydrogen economy in Wales and ways in which Wales could gain an advantage through the transition. The information from this consultation exercise and the views of the participants have been collated into a vision of a hydrogen economy for Wales and a route map defining potential strategic development towards the hydrogen economy in Wales, including the requirements for the successful introduction of a hydrogen economy in Wales.

Key Points

- Hydrogen has a significant part to play in Wales overcoming its increased dependency on the diminishing resource of imported fossil fuels by providing a more sustainable alternative and increasing efficiencies.
- As an energy carrier, hydrogen can also significantly reduce the problem of Wales's greenhouse gas emissions and atmospheric pollution, especially if it is produced using renewable energy.
- Hydrogen is an ideal complement to electricity as an energy carrier. It can provide the required buffer between consumer demand and intermittent supply of renewable electricity from wind, solar or marine sources. As Wales increases the provision of renewably produced electricity, this balancing function will become more important.
- The transport sector has the fastest growing demand for energy in Wales, yet it is currently almost entirely dependant on fossil fuels. Hydrogen produced from renewable sources has the flexibility to be used as a clean, safe and convenient transport fuel.
- In contrast to fossil fuels, the resources to produce hydrogen are not limited to any country or region and a number of different technologies appropriate to the location can be used to produce the hydrogen. In Wales this includes electrolytic hydrogen produced from wind, solar and marine electricity and from biomass.
- Transition to a hydrogen economy in Wales cannot be seen in isolation from the rest of the world. Collaboration with other regions of the UK and on an international scale will be necessary to overcome a number of the technological barriers that are currently faced in moving to the hydrogen economy. Wales should seize the opportunities available to become a significant global player in a future hydrogen economy. This ambition is not unrealistic if the latent ability and resource in Wales is put to work.

- The potential demand for new products and services in a hydrogen economy suggests that Wales can benefit significantly in economic and social terms. This benefit can come not only from a transition in Wales itself, but also through the establishment of new Welsh industries, hence new Welsh jobs and income from exporting hydrogen energy related technology and services to the rest of the world. The Hydrogen Valley initiative is targeted at the establishment of these new industries in Wales.
- The current emphasis of hydrogen energy development is on technology, but without consumer demand promising hydrogen energy technologies may fail, as have numerous examples before. Significant efforts are required to increase public awareness, understanding and acceptance before a market pull towards the hydrogen economy can be established.
- Early demonstration projects have a fundamental role to play in addressing these issues of public acceptance, whilst proving the technologies to be employed
- The level of fuel duty in the UK means that untaxed hydrogen, particularly from renewable sources, is a more competitive fuel in the UK than almost anywhere else in the world.
- The transition to a hydrogen economy will require a number of intermediate steps, rather than a single step change. These transition steps include the adoption of hydrogen as an additive to conventional fuels like diesel or CNG for internal combustion engines, electric vehicle drive development, hydrogen storage improvement and fuel cell developments. The Hydrogen Valley initiative encourages and supports organisations developing these transition technologies in Wales.

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1. Introduction

This document outlines the way in which the development of a clean hydrogen energy economy accompanied by the development of efficient enabling technologies can play an important part in achieving a sustainable energy future in Wales. At the same time, the document identifies the ways in which Wales can gain advantage in the soon to emerge world markets for hydrogen energy technology.

The document has developed from a number consultations with the major stakeholders in the future hydrogen economy in Wales, especially at two seminars held in March and June 2004. These workshops and the subsequent collation of this document have been a result of the collaboration between the WDA led Hydrogen Valley Initiative and the Cymru H2 Wales project of the University of Glamorgan's Hydrogen Research Unit.

Towards the Hydrogen Economy in Wales

Imagine. . .

- *Wales utilising its natural energy resources to meet all of its energy needs.*
- *Wales not being dependant on imported fossil fuels.*
- *Transport in Wales that does not emit CO₂ or significant levels of any other pollutants.*
- *A thriving Welsh industry based on the manufacture of cutting-edge energy and automotive equipment.*
- *A flourishing rural economy in Wales that gains a significant amount of its income through the cultivation of energy crops.*

However, at present this vision is some way from reality. Global demand for energy continues to grow dramatically. Whilst predictions vary, this trend is likely to continue for the foreseeable future. The bulk of this increasing energy consumption is being met from diminishing reserves of fossil fuels, resulting in continued emissions of carbon dioxide and other atmospheric pollutants. Wales has followed this trend, with the significant majority of our energy needs currently being met from non-renewable sources. Over the last thirty years the most significant increase in energy consumption has been in the transport sector, which remains almost entirely dependant on fossil fuels.

“ Hydrogen has the greatest potential to deliver a low carbon economy future as a fuel source for both the energy and transport sectors”

Rt.Hon. Rhodri Morgan

There is increasing recognition that hydrogen has great potential to overcome the problems that accompany carbon based energy forms and to achieve the vision of Wales presented above. As an energy carrier, hydrogen can reduce the dependency on fossil fuels and in turn reduce greenhouse carbon dioxide (CO₂). Hydrogen, when produced from renewable means can be burned as a fuel, e.g. in an internal combustion engine, releasing no CO₂. Better still, when used in a fuel cell, the energy recovery from the hydrogen is more efficient and will not release other pollutants such as nitrogen oxides. Hydrogen can be produced from a large number of readily available sources, including water, crops and waste products, as well as from fossil fuels. In addition, hydrogen can provide an effective energy storage mechanism for intermittent renewable energy sources like wind, wave, tidal or solar.

The combination of hydrogen with fuel cell technology carries great promise for a cleaner, more efficient energy future, particularly for the automotive sector, but also for static energy generation and mobile power applications. Since Sir William Grove of Swansea invented the fuel cell in 1839, the technology has remained largely underdeveloped. That is until recently. Over the last ten years, fuel cell technology has emerged from the laboratory to an initial commercialisation stage, with a number of organisations introducing products to early niche markets. Wales, with its expertise in the automotive and high technology sectors and supportive business climate, is ideally placed to take advantage of this emerging industry. The Hydrogen Valley project provides the perfect stimulus for the establishment of a Welsh hydrogen and fuel cell industry, with the potential to secure early mover competitive advantage for firms in Wales.

Hydrogen Valley Vision

“To achieve a zero emission energy based economy, supported by a sustainable business community, through the exploitation of leading edge technologies and stimulation of emerging niche markets.”

A vision of a hydrogen economy for Wales is not one that can be considered in isolation. The magnitude of the required change means that progress needs to be synchronised with the rest of the UK, with Europe and the wider world for a sustainable hydrogen economy to become a reality. The supportive policy framework in Wales in pursuit of cleaner energy is entirely in step with activities in the rest of the UK, Europe and the rest of the World. Some countries have already taken the first steps towards a hydrogen economy. The USA, Canada, Japan and Germany all have established programmes. Significantly for Wales, smaller countries like Iceland have also demonstrated that the development of a hydrogen economy is not just the preserve of large economies. If the actions proposed in this report become a reality, Wales will be firmly placed on the hydrogen energy map. Actions such as the early establishment of working demonstration projects, building on Wales’ existing strengths, will represent a significant step towards realising the vision of the National Assembly for Wales to become a showcase for renewable energy.

“The Hydrogen Economy is not going to happen tomorrow, but if it happens in the next 20, 30, 40 or 50 years time, as I think most people accept it almost certainly will, because it will have to in terms of controlling global warming, the greater the contribution that we have made [in Wales] the better.”

Rt.Hon. Rhodri Morgan

2. Hydrogen: Future Energy Vector

The Carbon Energy Problem

Demand for Energy

Worldwide energy demands are likely to double over the next 50 years, driven by increasing population and economic growth particularly in the developing countries. At the same time, reserves of oil have passed their peak in most producing nations. The majority of the remaining oil is in the potentially unstable Gulf states. Natural gas demands are also growing and despite our natural gas reserves in the North Sea, the UK is set to become a net importer of natural gas in the next four or five years. The results of this are already reflected in many recent price rises. Whilst demand for energy in Wales is not growing at the pace of certain countries like China, if we continue on our present course for sourcing our energy needs, the competing demand for finite fossil fuel resources will lead to significantly increased energy costs and potential economic difficulties. Recent evidence shows that uncertainties over oil supply from the middle-east and increasing world demand has created an upward pressure on oil prices. Over time this could have significant economic impact. A country that is self-sufficient in cheap renewable energy should have economic competitive advantage.

Security and Continuity of Supply

Recent damaging power cuts in many parts of the world have highlighted the potential problems when demand cannot be satisfied by supply, or where significant centres of population are dependant on a centralized energy infrastructure. The effect of power black-outs in Cardiff, for example, similar to those experienced in the North Eastern US, Italy and London over recent years, could have a damaging economic impact. The fuel blockades of September 2000 and oil crisis of the 1970s also demonstrated the extent to which our economy is currently dependant on continued supplies of fossil based fuels and the potential difficulties surrounding even short-term interruptions to supply. Without changes to our energy provision, the issues of security and continuity of supply will become more significant. Recent events in Iraq and Russia supports the argument that security of supply is becoming a greater threat, causing some countries to stockpile and further force up energy prices.

Global Climate Change

The overwhelming balance of scientific evidence supports the belief that emissions from human activity are having a detrimental effect on the world's climate. The most prominent of these emissions, carbon dioxide, is an unavoidable consequence of our inexorable use of hydrocarbon fuels. Without drastic reductions in the amount of carbon dioxide that we release from our activities, there will be dramatic and potentially disastrous consequences for our global climate and result in a devastating impact on human life. Climate change in Wales has the potential to adversely affect natural and cultural habitats, have a bearing on health, and damage the Welsh economy. This is a global problem, with dramatic local impacts, but it is also an area where we can play a significant role in developing and demonstrating solutions.

Poor Air Quality

The absence of visible smog from most parts of Wales conceals the persistent problem of invisible oxides of nitrogen, carbon monoxide and micron scale particulates emitted from our vehicles and industry. Up to 24,000 people are estimated to die prematurely each year in the UK due to the effects of air pollution. Traffic in Wales' towns and cities, and our industry currently contribute to poor air quality and consequently to health problems for the people of Wales. To overcome this, we in Wales, as in the rest of the world have an obligation to devise and use clean energy solutions, particularly for transport. Use of hydrogen as a vehicle fuel can dramatically reduce or eliminate these harmful emissions.

The Hydrogen Energy Answer

Abundant supply

Supply of hydrogen is virtually inexhaustible and can be produced in several ways from many primary energy sources. Unlike coal, oil or gas, hydrogen cannot be mined, or pumped from the ground, but has to be extracted from water or organic compounds by using an external energy source. Hydrogen can therefore be considered an energy carrier, like electricity, rather than a primary energy source. In contrast to fossil fuels, the resources to produce hydrogen are not limited to any country or region and a number of different technologies appropriate to the location can be used to produce the hydrogen.

Flexible fuel

Hydrogen can be burned as a clean efficient fuel, emitting water and no CO₂. This property can be utilised in internal combustion engines and also allows hydrogen to be mixed with more traditional vehicle fuels, such as diesel, petrol or natural gas to extend the lean flammability limit of conventional fuels to achieve higher thermal efficiency and lower exhaust emissions. Alternatively, hydrogen can be used in a fuel cell to produce electricity, potentially achieving higher efficiencies than combustion processes. Hydrogen is versatile enough to provide power for buildings, transport or for portable equipment.

Enhancing Renewables

Widespread application of renewably produced electricity, appropriate to local resources is an important way to address many of the problems of the carbon-based energy. However, most forms of renewable energy are intermittent be they wind, solar or marine and require some form of long-term energy storage to allow supply and demand to be matched. Hydrogen, used as an energy carrier in conjunction with renewable energy resources can provide an effective store for intermittent renewable energy, addressing the imbalance between supply and demand. Renewably produced hydrogen can also enable us to maintain the freedom that we currently enjoy for personal transport, whilst achieving the necessary reductions in carbon dioxide and other emissions.

Hydrogen Energy Security

The relative abundance of hydrogen from sources readily available in Wales and the availability of numerous production techniques mean that hydrogen can start to displace oil products, particularly in the transport sector. Whilst the transition will not be immediate, there is plenty of scope for early introduction of hydrogen via mixed fuels in combustion engines. This will help to build a hydrogen production and distribution infrastructure in Wales and in turn reduce our dependence on foreign sources of oil.

Pollution Reduction

Renewably produced hydrogen used in conjunction with a fuel cell can dramatically reduce, if not eliminate the emission of pollutants such as carbon dioxide, carbon monoxide, oxides of nitrogen. Additionally, hydrogen when mixed with conventional fuels such as diesel or natural gas can dramatically reduce emissions, even when burned in an internal combustion engine. The reduction in atmospheric pollutants that hydrogen can bring about would result in markedly improved health for a significant number of people in Wales.

Other fuels in the energy mix

It must be emphasized that no one is advocating the entire energy system revolve around hydrogen. This could potentially waste a significant amount of energy. Instead, hydrogen should take an appropriate place within the overall energy mix and at the appropriate time. Clearly our immediate energy future will continue to be dependant on fossil fuels, with a transition away from oil towards natural gas a consequence of diminishing supplies. This is

particularly likely to be the case for transport (especially road transport), which is almost entirely dependent on fossil fuels at present. A whole-scale transition to hydrogen as a transport fuel is unlikely in the short term, particularly due to the absence of a viable hydrogen-refuelling infrastructure. The best way to overcome this hurdle is to progressively adopt hydrogen mixture fuels, such as natural gas/ hydrogen mixture or hydrogen injected diesel engines. These will allow the development of a hydrogen-refuelling infrastructure with time prior to the widespread introduction of pure hydrogen fuelled vehicles (combustion engine or fuel cell).

The Renewables Obligation, and policy commitments in Wales place a requirement for increasing proportions of our electricity to be sourced from renewable energy. Where possible, it is thermodynamically better for this energy to be used in the form of electricity. However, the variability of most renewable sources suggests that balancing supply and demand on the grid will be a significant issue, particularly as the proportion of renewables increases. Hydrogen, amongst other mechanisms, can have a role in storing energy during periods of excess renewable electricity production and releasing when there is a shortfall. Hydrogen scores over many other storage mechanisms in that the hydrogen produced can be used flexibly for conversion back to electricity, or for transport.

Bio fuels may also have a part to play in a future energy mix and can contribute to our transport fuel requirements in Wales. Hydrogen can also be produced from biomass resources, either grown or from “waste” streams. In many cases this will be accompanied by co-produced methane, which lends itself to a hydrogen/ methane mixed fuel application, particularly for heavy vehicles. More work is needed to determine the most appropriate use of biomass within the energy mix in Wales. However, the production of hydrogen from biomass provides a number of promising economic possibilities, not least for rural Wales.

Nuclear energy will continue to play a role in the energy supply for Wales for the rest of this decade. British Nuclear Group’s Wylfa power station on Anglesey is due to cease production of electricity in 2010, subject to continuing satisfactory safety reviews. Although nuclear power production does not give rise to carbon dioxide *per se*, unattractive economics and ongoing concerns about nuclear waste mean that the building of new nuclear power stations is not currently supported by the UK government. However, changes to this decision in future have not been ruled out, particularly if the major introduction of renewables into our energy mix is delayed.

3. Wales' Advantage in the Hydrogen Economy

Wales as a Sustainable Energy Showcase

The national economic development strategy of the Welsh Assembly Government “A Winning Wales” established the objective of making Wales a global showcase for clean energy development and energy conservation. Yet, at the current time, Wales and the rest of the UK lags behind a number of other developed countries in bringing clean energy schemes to fruition in general and realising the importance of a hydrogen energy future in particular. A significant amount of research and development funding has been applied, particularly in USA, Japan, Canada and Germany amongst others. There are a number of benefits resulting from this R&D funding for the countries involved. In particular, there is the core number of organisations in each country that have achieved technology advantages and early niche market dominance.

However, the transition to a hydrogen economy will not take place in these few countries alone, it will be a global movement. Admittedly, some countries will move at a different pace to others and some countries will extract greater benefit than others from the transition. It is our purpose to ensure that Wales is at the forefront of the countries to benefit from the development of a hydrogen economy and that organisations involved in the development contribute significantly to the economy in Wales.

Energy and the future economy in Wales

Wales, like every country in the world depends on a plentiful supply of adequately priced energy to ensure the competitiveness of industry, to power our homes, schools and hospitals, and to enable the mobility that has become an accepted part of modern life. As the 21st century unfolds, provision of this energy will become an increasingly important issue as competition grows for diminishing oil and gas resources and as the impacts of climate change and poor air quality are realized and understood.

In the nineteenth and twentieth centuries, energy, particularly coal, had a pivotal role in the economy in Wales. In the twenty-first century, energy will continue to play an important part in the Welsh economy. Utilising our abundant indigenous renewable resources, particularly wind, tidal, wave & biomass and capitalizing on our distinctive competences in automotive, chemical, materials, high-tech and agricultural industries can give Wales a distinctive advantage in the development of new energy industries and specifically in a future hydrogen economy. The strong automotive sector in Wales is of particular advantage in the development of industry for hydrogen and clean energy transport. If automotive organisations in Wales can be encouraged to embrace the development and commercialization of hydrogen and related enabling technologies, then there can be a bright future for the sector. Conversely, if nothing is done and focus remains on existing fossil fuel based engine technology, there could be a major threat to future jobs in the automotive sector in Wales.

Exploiting Wales' Advantage in the Hydrogen Economy

Wales already has a hydrogen industry, satisfying the demand for hydrogen for metals processing, petroleum refining, chemical manufacturing, semiconductor manufacturing, pharmaceuticals, glass production and the food industry. However, the scale of this industry is relatively limited when compared to the eventual demands of a full hydrogen economy and the current hydrogen production is entirely based on fossil fuel conversion via steam methane reforming. Nonetheless, Wales is unique in the UK in that this hydrogen production is relatively evenly spread along the main transport route (M4) serving the major centres of population in Newport, Cardiff and Swansea. This existing hydrogen infrastructure could form a platform for an early hydrogen micro-economy in South Wales, particularly if added to with additional renewable production to provide supply nodes for early hydrogen transport fleets.

Worldwide experience of hydrogen, its production and utilisation is limited. However, Wales does possess expertise in hydrogen and in a number of related areas that can be used in the development of a hydrogen economy in Wales.

The wealth of renewable energy resource in Wales could satisfy all our future hydrogen requirements, both for transport and to power our homes and businesses. However, at present this would not be economically sensible. At present, renewably produced hydrogen is between two and four times as expensive as fossil fuel based hydrogen. Further developments of fossil fuel based hydrogen need to be balanced against the overall CO₂ benefit. Further research and development is ongoing to reduce the cost of renewable hydrogen and in parallel to capture the CO₂ produced from fossil fuel routes.

Team Wales

The Welsh Assembly government supports the development of renewable energy in Wales, and sees the development of renewable energy as a source of employment. Combined with the close co-operation that exists between industry, academics and government agencies, Wales has the opportunity to take a leading role in the development of sustainably-produced hydrogen and be at the forefront of the technology export market. Wales is a big enough nation to carry out actions that count, but small enough to ensure that national networking is effective.

4. A Timeline to the Hydrogen Economy in Wales

The transition to a hydrogen economy in Wales can be characterized as follows:

- Phase 1 Development and demonstration of technologies, establishment of policies and stimulation of early demand
- Phase 2 Commercial exploitation of early markets and creation of public acceptance
- Phase 3 Market growth, establishment of supporting infrastructure and sustainable production routes
- Phase 4 Achievement of the hydrogen energy vision

Expanding on these phases:

Phase 1

(Now – 5yrs)

Technology Development and Demonstration

Significant hydrogen energy R&D progress is being made internationally and Wales is currently making some important contributions to this. Successful early steps towards a hydrogen economy will depend on a combination of indigenous research, development and deployment of hydrogen technologies and the early adoption of new technology developed elsewhere. The strength of existing automotive industry in Wales, coupled with the links between Wales and the rest of Europe, USA and Japan can all be beneficial in attracting early hydrogen energy developments to the country.

The development and deployment of hydrogen enabling technologies into operational demonstration projects is important for the early stages of a hydrogen economy in Wales. As well as proving technology in a real world situation, high profile demonstration of hydrogen technology builds public awareness and confidence in the technology to be employed. Not all demonstration projects have to be world firsts as there are significant benefits to be gained by proving the technology in Welsh conditions and through the exposure of the public in Wales to new technologies. Early steps would include proving the concept of hydrogen as a transport fuel in Wales, in a range of different vehicles. Whilst there is significant merit in the development and demonstration of fuel cell technology in vehicles and for stationary applications, hydrogen in combustion engines will provide a useful bridging technology. Wales possesses one of Europe's largest car engine plants and numerous component and sub assembly suppliers. This significant expertise in the design, development and manufacture of internal combustion engines suggests that Wales could be at the forefront of hydrogen ICE development.

Significant benefit can be achieved by the early creation of flagship centres, spread throughout Wales for the demonstration of future hydrogen focused transport and energy technologies. Together with the right economic incentive this would provide encouragement of leading edge technology businesses to locate in Wales. Such centres would provide a base for the development and demonstration of commercially viable vehicle products and domestic products as well as being the foundation for a high profile technology based cluster, incorporating combustion and fuel cell applications.

Policy Establishment

The transition to a hydrogen economy in Wales requires policy direction that embodies the principles of sustainable development for future energy supplies. Built into its constitution through section 121 of the Government of Wales Act, the Welsh Assembly Government has a

binding legal duty to pursue sustainable development in all it does. On the basis of present day costs, it would be difficult for hydrogen energy to compete against current, more polluting technologies. Hence energy policy in Wales must include the environmental costs of energy provision and use.

As it is extremely unlikely that the hydrogen economy can be achieved by Wales acting alone, there needs to be consistency with policy from Westminster, from the European Parliament and internationally. This extends from the application of codes and standards to regulatory and fiscal policies and financial support to nurture the development of hydrogen and alternative clean fuels and energy systems. Hydrogen energy policy in Wales needs to provide a degree of long-term consistency to allow investors and other organizations to manage their investment risk.

Stimulation of Early Demand

In addition to existing strengths in the automotive industry, fiscal measures and financial support, early demand for hydrogen will be stimulated by the provision of a useable hydrogen supply infrastructure. Although hydrogen exists in greater industrial volume on Teesside, Wales is unique in the UK in the existing spread of hydrogen infrastructure from Newport to Swansea, along the M4 corridor the countries major transport route. Most commentators recognize that early hydrogen transport developments are likely to be based around fleet vehicles returning to a central base. Council vehicles, bus fleets, refuse vehicles and airport vehicles are all examples suitable for early conversion to hydrogen technology. Although existing hydrogen assets are operated by a number of organizations, there is the potential for Wales to overcome the early infrastructure problems that other regions may face.

Phase 2

(5-15 yrs)

Commercial exploitation of early markets

For any market to develop, the technology-push from researchers, developers and manufacturers needs to be overtaken by customer-pull. Clearly one of the most significant factors that allows for this transition to take place is the reduction in cost of the new technology, when compared with existing alternatives. Hydrogen vehicles, powered by internal combustion engines or by fuel cells are available today, but current costs of such vehicles are prohibitive for consumer uptake. Component costs, hence vehicle costs will reduce significantly if mass manufacture can be adopted, but in the mean time developers will continue to need support to develop cost competitive products.

Turning to the hydrogen itself, it is often argued that hydrogen is much more expensive than existing fuels. This may be the case in countries where fuels are lightly taxed, such as Canada, USA or Australia. However, in the UK, the level of fuel duty means that untaxed hydrogen (particularly from fossil fuel sources) would be competitive on an energy basis with petrol or diesel. Accepting that fuel costs alone play only a minor part in most vehicle purchasing decisions, this is potentially a source of advantage in the early development of a hydrogen economy in Wales, allowing stimulation of early markets and allow organizations in Wales to establish early market experience and advantage.

Public acceptance

Consumer pull is unlikely to occur without acceptance of a technology as something desirable, impossible where there is no awareness and understanding. Three critical factors are required to address the issue of public acceptance; these are *education*, *marketing* and *exposure to the product*.

The incorporation of the benefits of hydrogen energy in the context of broader alternative energy teaching in schools would capture those still within formal education. However, there

is also a need to inform people that are no longer in formal education and exhibits, road shows and other accessible means of information would be useful in this respect.

Effective marketing, on the benefits of hydrogen in general as well as on specific products has the possibility of creating awareness and influencing the public. Both education and marketing of this general nature will require a combination of government policy direction and input from commercial organizations.

The current dearth of hydrogen energy demonstration projects in the UK (particularly when compared to Germany, Canada or USA where numerous examples exist) means that there is almost no public exposure to the product and hence little public awareness of the benefits of hydrogen as an energy carrier. The broader inception of hydrogen energy demonstration projects, made accessible and welcoming to the public will help to move from awareness to acceptance and finally to demand.

Phase 3 (15-30yrs)

Market growth and establishment of supporting infrastructure

By this stage it is anticipated that technological progress will have reduced the cost of hydrogen energy products to a level where products become attractive to more than small niche markets. At the same time demands on reducing fossil fuel resources are likely to make hydrogen a more attractive fuel alternative.

The development of numerous demonstration and development projects, typically based around tied fleets progresses to the creation of a viable infrastructure for consumer utilization. The small number of strategically located hydrogen supply sources coalesces to a national network of hydrogen supplies, throughout Wales, the rest of the UK and Europe.

Whilst it may seem to be obvious that this will happen slowly and incrementally, the sizeable investment required for auto manufacturers to establish the mass market vehicle products required in this phase, may mean that the step up to a workable infrastructure occurs more quickly than anticipated.

Sustainable production routes

Much of the hydrogen to satisfy early demands is likely to come from hydrocarbon sources, probably from steam methane reforming or partial oxidation of oils. However, in anticipation of stricter legislation on CO₂ emissions, these technologies will need to incorporate carbon sequestration, adding to their cost. Production from hydrocarbons will also suffer from increasing feedstock costs. Hydrogen production from renewable sources will become more attractive commercially and environmentally and starts to compete with the production of fossil fuel based hydrogen. Local, distributed production obviates the need for the development of extensive national hydrogen distribution networks in Wales. Where hydrogen pipeline networks do exist they are cost competitive with distribution of energy by electricity.

Planning rules and administrators will also become more familiar with hydrogen energy applications and current over-caution will be replaced by rationalized consent procedures. The development of recognized international codes and standards support this transition.

Phase 4 (30yrs +)

Achievement of the hydrogen energy vision

Hydrogen will eventually displace fossil fuels as the fuel of choice in Wales. The range of renewable means to produce hydrogen will be enhanced by the introduction of biological processes that provide impetus to agriculture in Wales and regenerate the rural economy.

Hydrogen production processes are numerous and appropriate to local resources. A truly national and international infrastructure for hydrogen will exist. Despite growth in global population and energy demands, this energy burden is met with significantly lower levels of CO₂ emission than at present.

Companies from Wales having established expertise and experience in hydrogen energy are exporting products worldwide, making a significant contribution to the economy in Wales and providing a significant level of high skilled jobs.

5. Requirements for the successful introduction of a hydrogen economy in Wales

Technical Requirements

- **Technology Focus** - On-going research is required to identify the most promising/likely technology options for exploitation by Wales and in the rest of the UK. This should only be undertaken in Wales where there is specific advantage in doing so, avoiding unnecessary duplication with research conducted elsewhere. Research should be aimed also at providing better focus for the deployment of limited resources.
- **Technology Piloting/Demonstration** – Demonstration projects should be selected and designed to maximise the promotion of potentially commercial products in order to encourage maximum private sector investment. Accordingly demonstration projects should be supported by market evaluation that confirms a high degree of market potential contributing to a more likely product launch and roll-out. This focus will make lobbying of EU/Government organisations for grant support more effective and likely to succeed.
- **Energy Density** – Current problems with hydrogen storage density force a route to development that is focused on hydrogen supply limitations. Market opportunities have to be developed that can function within the limitations of hydrogen storage and an embryonic infrastructure and create a growth industry that will encourage subsequent investment in an expanding infrastructure.
- **Life Cycle Understanding** – Full life cycle analysis will be required to identify those transport technology options that provide a balanced potential for commercial exploitation with positive environmental impact.
- **Synchronisation of Technologies** – The route to a hydrogen economy requires the synchronisation of technology development in relation to fuel production, bulk fuel storage and transportation, fuel decanting, ‘on-vehicle’ storage and power train systems. The speed of development and introduction is dependent on the slowest element and significant investment in any single part that takes it ahead of the collective game could be wasted and even damaging to the organisation concerned. Joint project management through a significant cluster may reduce the potential for such a situation. Such a cluster may extend beyond Wales geographic boundaries to have sufficient size.
- **Fuel Cell vs. IC** – Market drivers will determine if and when fuel cell technology is commercially viable in transport applications. Transitional technologies in the form of IC powered electric hybrid vehicles are already in production and volumes are

rapidly becoming commercially viable. Hydrogen blend IC engines have the potential to provide a useful bridge to future pure hydrogen and fuel cell vehicles, particularly through the cost effective introduction of a hydrogen infrastructure. Pure electric vehicle technology is also improving and further development of electric drives will help with the introduction of fuel cell based power trains.

- **Safety and Standards** – There needs to be close co-operation with all bodies that can influence or implement safety standards and provide guidance to suppliers and customers alike, both nationally and internationally.
- **Market Acceptance** – Products need to be developed and demonstrated to create a niche market demand in the first instance that can be supported from a very limited infrastructure. That in turn should create a market pull that will justify investment in infrastructure and more generic products.
- **Infrastructure** – Key players in Wales with existing hydrogen production facilities need to be brought together to develop a joint plan for the exploitation of hydrogen powered transportation and creation of standard filling facilities across South Wales as a first step to a corridor along the entire length of the M4.
- **Skills** – Skill shortages are potentially as great a barrier as any. Academic institutions must be fully integrated into the transition to ensure that appropriate courses are developed and promoted to respond to this emerging industry's people requirements.

Political Requirements

- **Political Leadership** – Political leadership stems from a clear vision and viable strategy. If this can be developed then it provides an ability to set targets which stand a real chance of being carried forward. The combination of environmental issues and sustainability of fuel supply provides a powerful case for taking this activity forward whatever the political scenario. Key stakeholders, including the Hydrogen Valley initiative, must work to provide the Assembly with a vision that is easily translated into a strategy, thus facilitating leadership.
- **Networking** – key players in the future hydrogen economy in Wales have been brought together through projects such as Hydrogen Wales and the Hydrogen Valley initiative. It is critical that these opportunities to network are maintained if Wales is to gain an advantage through the transition to a hydrogen economy.
- **Opposing Interests**– Vested interests have the power to influence for good or bad the support for activities necessary to take development activity forward. Interested parties should work together to maximise positive influence in the political arena. This is particularly the case with major energy industry players and OEM automotive manufacturers.
- **Energy Options** – The confusion about the selection of the most appropriate fuels for transition or long term operation is leading to a 'wait and see' approach. The vision and strategy must develop to include informed recommendations regarding potential transitional and long term fuel solutions.
- **Fiscal Policy** – Long term fiscal policy needs to be adopted that give incentives to investment at the appropriate time in transitional technologies and fuels.

- **Local Politics** – Relationships must be developed with those local authorities most receptive to supporting these technology/community developments. As activities and their benefits become apparent then more authorities will want to participate.
- **Legislation** – All appropriate government organisations should be engaged to advise and promote the need for health & safety as well as environmental legislation to catch up with hydrogen potential for domestic and private transport and energy applications.
- **International Competition** – Wales cannot compete with the level of funds being deployed by the governments of USA, Canada, Japan and Germany. However, we can provide an environment for their companies to develop and test the technologies and perhaps share their knowledge with local companies.

Economic Requirements

- **Raising Capital Funds** – Early stage project capital funds are difficult to raise. Availability of EU/Govt finance is patchy. We need to present a strong strategy for the development of commercially viable products and an embryonic infrastructure. A holistic approach to the development of a Hydrogen Economy is more likely to attract grant funding and thus private sector investment.
- **Cost of Alternatives** – Even with energy costs rising they are still relatively cheap compared with the current cost of hydrogen. This favours the status quo requiring consideration of the mitigation of costs for specific demonstrations or commercial applications as well as continuing to support research into the commercial production of sustainable hydrogen.
- **Lack of Customer Demand** – Many local authorities are keen to be seen as market leaders in the application of clean vehicle technologies. Depot based local delivery fleets lend themselves to an emerging niche urban delivery vehicle market that can with fiscal support become viable very quickly.
- **IPR Protection** – Advice and support on the schemes available in Wales to subsidise IP application can be provided by the Welsh Development Agency.
- **Infrastructure Investment** – This is the largest single problem requiring a long term approach. Investment in pilot infrastructure schemes by key industrial players may be possible to develop limited commercially viable activity. This is likely to require some support from grants to take place.
- **High Costs of Technology** – All stages of hydrogen technology are currently too high to be competitive. However, it may be possible to identify very local projects where conditions allow developments to proceed commercially. These need to be supported to begin the process of creating critical mass necessary to develop competitive costs.
- **Regional Advantages and Disadvantages** – Wales has a small population and comparatively small economic strength. However, its population distribution, location, geography, political structure and existing hydrogen infrastructure make it an ideal place to pilot a hydrogen economy. Doing so could bring economic, technology, and environmental benefits disproportionate to the level of investment required.

- **Knowledge/Expertise** – To draw activity to Wales will require the relocation of expertise which is currently in short supply. However, by becoming a leading pocket in Hydrogen activity it provides Welsh universities with the opportunity to become centres of excellence for these emerging technologies and markets with broader commercial economic gain.

Social Requirements

- **Cultural Acceptance** – As a matter of priority, public demonstrations and educational events must be developed to begin the process of gaining public acceptance of hydrogen and its safety. Limited efforts have already started in Wales.
- **Understanding** – Understanding of the benefits and needs of a transition to a hydrogen economy because of energy sustainability and the environment there will eventually produce a demand for it to happen.
- **Transport Strategy** – There is currently a lack of a fully integrated transport infrastructure in Wales. Regional and local government and significant transport companies should be encouraged to work together to develop such an infrastructure and at the same time identify opportunities for the viable operation of alternatively fuelled transport.

Environmental Requirements

- **Clean Bulk Hydrogen Production** – Wales should be at the forefront of achieving the economic production of sustainable hydrogen from carbon neutral processes. Wales's expertise in hydrogen production from biomass is potentially an area of strong competitive advantage
- **CO2 Sequestration** – If this process is feasible and safe then it could have a significant impact on the speed of transition as Hydrogen can be produced from existing hydrocarbon stocks until clean hydrogen becomes economically viable. Progress on this issue needs to be closely monitored.
- **Material/Chemical Issues** – The impact on the reliance on precious metals in fuel cells and chemical hydrides needs to be understood. This may affect the selection of the preferred technology option so again progress on this issue must be closely monitored.
- **Environmental Perception** – The visual impact of renewables, NIMBYism provides a substantial barrier. Projects need to be developed in acceptable locations and with a positive visual impact. Consideration must be given to raising awareness in the delivery of all projects with the people directly involved or affected.

Conclusion

The transition to a fully-fledged hydrogen economy is not going to happen overnight. However, increasing global energy demand, competition for diminishing oil and gas reserves, the need to address global climate change and local pollution all make progress towards a hydrogen economy probable if not inevitable. Wales, like every country needs to address these issues. The choice we now face is whether Wales takes a leading role in the path towards a cleaner hydrogen energy economy or whether we choose to follow behind the leading nations in this endeavour.

Wales has a number of advantages that can be utilized in the transition to a hydrogen economy:

- Our abundant renewable resources provide an opportunity to clean up our energy system. However, one major part of our energy demand is still almost totally dependent on oil-based products, namely transport. Combining our renewable assets with the production of hydrogen can start to overcome the dependence of our transport sector on oil and provide significant environmental benefits.
- We possess exceptional competence in a number of industries with direct relevance to the hydrogen economy, namely the automotive, chemical, metals, and micro-electronic industries as well as our long-standing expertise in agriculture. To turn this to our competitive advantage will require vision, collaboration and determination.
- The National Assembly for Wales (NAfW) has a distinctive statutory duty to promote sustainable development and has set challenging goals for the adoption of renewable energy, seeks to promote renewables to enhance industrial, rural and commercial opportunities and positions Wales as a renewable energy showcase.

What matters now is how we chose to use these advantages in pursuit of a cleaner future energy system. We face a number of challenges in the transition to a hydrogen economy, but this document has outlined how these challenges can be addressed and this transition can be to Wales advantage.