Written Evidence Submitted by the Birmingham Energy Institute (BEI), the Birmingham Centre for Fuel Cell and Hydrogen Research (BCFCHR) and the Birmingham Centre for Railway Research and Education (BCRRE) at the University of Birmingham

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Introduction

The University of Birmingham is ranked amongst the world's top 100 institutions. Its work brings people from across the world to Birmingham, including researchers, teachers and more than 6,500 international students from over 150 countries. The University has been challenging and developing great minds for more than a century. Founded in 1900, it now employs more than 7,000 staff and has an annual turnover of nearly £580 million. Characterised by a tradition of innovation, research at the university has broken new ground, pushed forward the boundaries of knowledge and made an impact on people's lives. In the UK-wide assessment of the quality of research in universities, 28% of its research was rated as world-leading and a further 53% rated internationally excellent.

The Birmingham Energy Institute (BEI) is the focal point for the University and its national partners, to create change in the way we deliver, consume and think about energy. The Institute brings together interdisciplinary research from across the University to deliver co-ordinated research, education and the development of international partnerships. With over 140 academics engaged in energy and energy related research and development, the Institute is driving technology innovation and developing the thinking required to solve the challenges facing the UK, as it seeks to develop sustainable energy solutions in transport, electricity and heat supply.

The Birmingham Centre for Fuel Cell and Hydrogen Research (CFCHR) was formed in early 2000 and is nationally and internationally recognised for its expertise in fuel cell technologies. The Centre focuses on research and development, applications and demonstrations of fuel cell and hydrogen systems and technologies. CFCHR is proud to be the largest academic group in the field in the UK and one of the largest worldwide, and the only research institution in UK integrating research work across the full spectrum of fuel cells and their fuels. It runs an internationally recognised programme of research into hydrogen as a future energy vector, and the development of key technologies, from sustainable production and hydrogen storage to commercial utilisation, as well as the efficient provision of electricity and heat from fuel cells.

The Birmingham Centre for Railway Research and Education (BCRRE) is the largest university-based centre for railway research and education in Europe. With over 145 academics, researchers and professional support staff, BCRRE provides world class research and thought leadership within railways alongside high-quality education programmes. It is part of the UK Rail Research Innovation Network (UKRRIN) and leads the Centre of Excellence in Digital Systems. Now almost 50 years old, BCRRE has developed a reputation for world-class specialist rail research and education. This was recognised by the award of the prestigious Queen's Anniversary Prize for Higher Education.

Executive summary

- Hydrogen and hydrogen-based fuels offer the potential to completely decarbonise the energy supply system.
- Unless overall energy demand is considerably reduced, it will be very difficult to cover UK energy needs from decarbonised sources.
- Investments in energy efficiency reduce operational costs, thus addressing anything from energy poverty to import dependencies, energy distribution network rebuilding, and renewable energy capacity building.
- Based on green hydrogen, a large number of hydrogen-based fuels can be derived that are fully compatible with the current energy system and allow a gradual and continuous phasing-in of clean zero-fossil-carbon energy carriers.
- However, there are a number of regulatory obstacles in the way of exploiting the low cost of producing green hydrogen based energy vectors.
- Potential new business models in the energy market will attract private investment, but this requires a long-term stable regulatory and political framework.
- Compared to the EU and countries like Germany, the UK lacks structures that deliver reliability, accountability, and long-term stability that is required for private investment.
- The number of hydrogen refuelling stations (HRS) in the UK is negligible with respect to the scale of development the Ten-Point Plan is calling for and the wish of the government to decarbonise transport. There needs to be a willingness on the part of industry to build this infrastructure, supported by a government strategic framework.
- The government has to realise that net carbon zero is not a target that will establish a sustainable energy supply system for the UK.
- A reduction in carbon emissions for heating is far more efficiently achieved by ambitious residential energy programmes, as hinted at in the Ten-Point Plan.
- Tyseley Energy Park in Birmingham is the largest scale production of green hydrogen in the UK. It is pioneering projects like this which are providing the platform for scaling up hydrogen production and utilisation.
- The HydroFLEX train is the first GB mainline approved railway vehicle to use hydrogen as its primary fuel and has paved the way for the whole industry to accelerate the programme of decarbonisation.
- Hydrogen fuel cell technology is an effective alternative to diesel engines in transport; potentially entirely carbon neutral in operation, hydrogen-powered trains more environmentally friendly while offering similar performance and potentially lower cost.
- Although UK hydrogen and hydrogen use technology companies are amongst the leaders worldwide, the number of such enterprises is far too low to establish a UK supply chain that is not subject to external influences from tariffs and conformity hurdles.
- A green hydrogen supply infrastructure will require a rethinking of the energy transmission system across Great Britain.
- The environmental (external) costs of a sustainable hydrogen-based energy economy will be far lower than with the current fossil technologies. This will not necessarily be the case for a net carbon zero scheme.
- The long-term advantages of energy independence will only be achievable if non-fossil energy sources are favoured within a plan for a sustainable energy economy.
- Hydrogen could make a valuable contribution to meeting Net Zero, but it should be seen as just one piece of the puzzle. Decarbonising the supply of energy is important, but we should also be determined to substantially reduce the overall demand for energy.

The suitability of the Government's announced plans for "Driving the Growth of Low Carbon Hydrogen"

We very much welcome the explicit inclusion of hydrogen-based energy carriers in the Ten-Point Plan presented by the government. This is a clear acknowledgment that hydrogen will contribute considerably to decarbonising the UK energy economy, leading to a sustainable system by 2050. Hydrogen and hydrogen-based fuels offer the potential to completely decarbonise the energy supply system. No matter what colour is peddled for the hydrogen, completely avoiding the extraction of fossil carbon and its subsequent conversion to carbon dioxide - which might or might not be captured and stored and might or might not then remain in storage for the required millions of years - is a goal achievable in the mid-term with the further falling cost of renewable energy.

What is more, current discussions are completely focused on today's energy supply. The fact that the Ten-Point Plan mentions building standard improvements for the first time is more than welcomed. Unless overall energy demand - and this includes a very large and fluctuating demand for heating in the form of natural gas - is considerably reduced, it will be very difficult to cover UK energy needs from decarbonised sources. The Swiss '2 kW society' model should be considered as a blueprint model for converting the energy economy. It has to be kept in mind that turning natural gas into hydrogen, combined with carbon capture and storage, will increase natural gas demand by about 30% - and this at a time where North Sea supplies are rapidly dwindling. This is therefore a recipe for increased import dependency. Investments in energy efficiency, by contrast, reduce operational costs, thus addressing anything from energy poverty to import dependencies, energy distribution network rebuilding, and renewable energy capacity building.

The Ten-Point Plan contains many technological elements that will be available in different time scales. Wind energy is currently the cheapest form of bulk electricity production worldwide. Photovoltaic electricity has become so cheap that it outcompetes individual residential grid electricity supply in practically all regions of the world. These are solutions that are immediately available, though they will require some investment into grid distribution and major investment into energy storage, for instance, by using hydrogen. The potential of usable wind energy in the UK by far surpasses the current electricity demand (by a factor of three). Other solutions to produce low carbon electricity have much longer time scales until they can contribute to a net zero carbon economy in a substantial way and require much higher investment. Implications on political and geographical dependencies created by the need to import 100% of fuel or being able to dispose of carbon and other waste have to be closely scrutinised. It also has to be kept in mind that heat and transport fuels can also be provided by other renewable energy forms than electricity. Heat recovery and use in district heating networks, as well as waste conversion to energy - to name but two elements of a future fossil-carbon free energy system - need to be considered. Pushing for a 100% zero-fossil-carbon economy by 2050 by reducing energy demand whilst building the renewable energy infrastructure will be by far the cheapest and fastest approach.

Green hydrogen is the keyword for sustainably decarbonising the energy economy. Based on green hydrogen, a large number of hydrogen-based fuels can be derived that are fully compatible with the current energy system and allow a gradual and continuous phasing-in of clean zero-fossil-carbon energy carriers. No investment into infrastructure or end-use is needed. Using carbon dioxide from biomass (biogas and gasification), waste, or even the atmosphere (driven by renewable energy), a fully sustainable carbon and energy circular economy can be achieved, integrating the markets for power, heating, and transport.

Whilst green hydrogen based energy vectors are those of choice, there are a number of regulatory obstacles in the way of exploiting the low cost of producing them. Adding the cost of grid transport to electricity converted to hydrogen in electrolysers makes the hydrogen excessively expensive. Producing hydrogen on sites of wind energy production avoids this, but adds the necessity for hydrogen transport. The complete system of charging for grid services and the handling of the respective transport monopoly needs to be addressed in a holistic approach to creating level playing fields for energy in the UK. The case of Ella Kissi-Debrah in London, where the death of a child from asthma in 2018 was directly linked to urban air pollution in the coroner's report, demonstrates that there is a case to answer for costing the environmental and public health impact of energy carriers and including this into their market prices (https://www.independent.co.uk/news/uk/home-news/ella-kissi-debrah-inquest-result-pollution-b1774841.html). After all, damage is sustained by the economy as a whole and compensation generally covered by the taxpayer. Charging the polluters for the full cost of extraction, distribution, and use of an energy carrier will create the competitiveness required whilst remedying the current market failure in energy carrier pricing.

The investment into a zero-fossil-carbon energy economy will be substantial. Potential new business models in the energy market will attract private investment, but this requires a long-term stable regulatory and political framework. The European Union has created this through the framework programmes, driving innovation through close cooperation with industry via the Joint Technology Platforms (JTIs). As the UK has left the EU, it has lost this long-term perspective. If major industry investment is to be involved, a stable and reliable framework is required for the UK. The Clean Hydrogen for Europe programme will coordinate all respective activities in the EU, based on the understanding that green hydrogen is the energy vector of choice to reach the COP climate goals. This involves an agency (currently the FCH Joint Undertaking) that organises the programmes around the transition, and manages and monitors progress. Other European countries such as Germany have similar institutions (NOW GmbH) which are organised as Public Private Partnerships. The UK lacks such structures that deliver reliability, accountability, and long-term stability that is required for private investment. The lead in Continental developments with more than a hundred hydrogen filling stations in service, 2 hydrogen trains in regular operation since 2018 with another 60 now ordered, is proof to the positive effect a well-structured and reliable political and regulatory framework can have on technical and commercial developments. The considerable progress of the Japanese and South Korean equivalents with over 500,000 residential fuel cell units sold into the markets are further evidence.

Hydrogen should also be linked to points 4, 5, 6 and 7 in the Ten-Point Plan. These are somewhat connected to hydrogen but this is not explicitly mentioned. All of these items require green hydrogen and hydrogen-derived fuels at the core of the solution.

The progress of recent and ongoing trials of hydrogen in the UK and abroad, and the next steps to most effectively build on this progress

London, Aberdeen, and Birmingham have and are trialling hydrogen fuel cell buses. These projects are/were successful demonstrations in the UK enabled by European funding. Similar efforts will now be needed to support the market introduction of fuel cell buses and other public transport and logistics vehicles with UK funding. The number of hydrogen refuelling stations (HRS) in the UK is negligible with respect to the scale of development the Ten-Point Plan is calling for and the wish of the government to decarbonise transport (see point 3.31 in the 2020 Spending Review). Judging from the scale of 100 HRS in operation in Germany currently, and the plans to have a network of 400 by 2023/2025, a government investment support programme of £50M to £100M is required to support the equivalent development in the UK, funding up to 250 HRS.

In order to do this, the UK needs to offer its own funding route comparable to the European funding. Dedicated agencies working closely with industry are required for the four nations. Ideally, these would coordinate general decarbonisation and energy efficiency measures in order to assure the 2050 goals are met. What is more, the government has to become aware that net carbon zero is not a target that will establish a sustainable energy supply system for the UK. Unless a sustainable system is installed, an imbalance of environmental impact, considerable cost to future generations (with no matching benefits), and substantial public health risks remain. A matched investment to the £240M for net zero carbon hydrogen and £81M for hydrogen heating will be needed for green hydrogen developments, amounting to an additional £350M in order to achieve a zero environmental and societal balance sheet by 2050.

Hydrogen for heating can be provided most easily by admixing up to 20% hydrogen into the natural gas grids. This will cause little to no disruption to end use appliances and minimal investment, if any. Above this level, end use appliances need to be adapted or replaced, requiring considerable private investment. The additional cost, though, is high since the (valuable) hydrogen will be competing with the lowest cost energy carrier available in the energy supply infrastructure, natural gas. Competing with transport fuels is far more compelling due to the far higher conventional fuel costs and low efficiency of conversion in combustion engines. A reduction in carbon emissions for heating is far more efficiently achieved by ambitious residential energy programmes, as hinted at in the Ten-Point Plan. This will also require far lower investment, accompanied by tremendously reduced energy bills, something that will also greatly reduce energy import dependencies in the mid term and make the UK energy markets more resilient.

Tyseley Energy Park in Birmingham has installed a 3 MW electrolyser connected to a biomass plant which produces 10 MW of green electricity. This is the largest scale production of green hydrogen in the UK. This hydrogen refuelling station is to be used by ~20 hydrogen buses procured by Birmingham City Council., starting Spring 2021. This is a development that is linked to a low carbon and low emissions refuelling station which is associated with the Clean Air Zone. It is pioneering projects of this type which are providing the platform for scaling up hydrogen production and utilisation. The next phase, presently being developed, is to establish a very large scale (~500 bus scale) hydrogen production plant which potentially utilise the green electricity and biogas for hydrogen production with a steam methane reforming plant with CO2 capture. This will have the capacity to deliver hydrogen into the local gas grid, for hydrogen for heat, distribute hydrogen for the CHP plants associated with the district heating system, decarbonising the Birmingham district heating system, and also large scale production of hydrogen for transport - rail and bus. The plans also extend to the utilisation of the low carbon refuelling hub to support the development of the hydrogen refuelling infrastructure for freight and logistics, as part of a wider regional plan to decarbonise this hard to reach sector. This would be a nationally leading demonstrator of the commercial deployment of hydrogen solutions for transport and heat.

The HydroFLEX train is the first GB mainline approved railway vehicle to use Hydrogen as its primary fuel. This major milestone has paved the way for the whole industry to accelerate the programme of decarbonisation, with several other companies and partnerships already committed to developing their own Hydrogen powered vehicles. The trials of the train, known as HydroFLEX and the UK's first hydrogen train have been supported with a £750,000 grant from the Department for Transport, follow almost two years' development work and more than £1million of investment by both the University of Birmingham and Porterbrook. Unlike diesel trains, hydrogen-powered trains do not emit harmful gases, instead using hydrogen and oxygen to produce electricity, water and heat. The ground-breaking technology behind the trains will also be available by 2022 to retrofit current in-service trains to hydrogen - helping decarbonise the rail network and make rail journeys greener and more efficient. The project involves the conversion of an existing Class 319 train, fitted with a hydrogen fuel cell, giving it the ability to run autonomously on hydrogen power on non-electrified routes. BCRRE with our partners at Porterbrook are accelerating our production design to enable the industry to benefit from this technology on a commercial scale in the short term future, this work is also being part supported by the Department for Transport. BCRRE are currently in discussions with Transport for West Midlands and West Midlands Rail Executive in supporting the Snow Hill lines project, and we are in early with regard to the potential introduction of the technology onto the network in the region. Transport currently accounts for around a quarter of the UK's greenhouse gas emissions and the UK Government has committed to reduce its carbon emissions by at least 80%, against 1990 levels, by 2050. Hydrogen fuel cell technology is an effective alternative to diesel engines; potentially entirely carbon neutral in operation, they are more environmentally friendly while offering similar performance.

The engineering and commercial challenges associated with using hydrogen as a fuel, including production, storage, distribution and metrology, and how the Government could best address these

Hydrogen and hydrogen use technologies are all available in the global markets. Although UK companies are amongst the leading companies worldwide, the number of such enterprises is far too low to establish a UK supply chain that is not subject to external influences from tariffs and conformity hurdles. The government has to commit to a stable and reliable commercial support and regulatory framework that will allow for long-term private investment to build the UK industry.

The main challenge, though, remains the level playing field. As the production and use of hydrogen causes considerable less environmental damage compared to any conventional fuel, but is not rewarded for this aspect, regulatory influence has to be taken on the energy markets to allocate the environmental damage of fossil fuel use to the polluters. Since a simple increase in fossil fuel prices will lead to a surge in energy poverty, a sustainable programme of support for improving energy efficiency has to be linked with respective increases in fossil energy prices. At a societal and macroeconomic level, the avoidance of cost for environmental and health damage will be more than balanced by the additional cost of hydrogen use, making hydrogen the overall cheaper choice on balance. Nevertheless, in the current market mis-allocation of damages, hydrogen is wrongly perceived as the more costly alternative. A well-designed market introduction scheme will be required here to navigate the challenging issues of introducing hydrogen as a bulk commodity. Regulation will certainly be one way to address this.

When integrating renewable energy production at a large scale, storage of electricity in the form of hydrogen will be one option for seasonal energy storage. Concepts for bulk storage and storage management will be required as demand rises.

The infrastructure that hydrogen as a Net Zero fuel will require in the short- and longer-term, and any associated risks and opportunities

A green hydrogen supply infrastructure will require a rethinking of the energy transmission system across Great Britain. Major transmission lines and hydrogen pipelines will be required to link Scottish wind power production to the English clusters of energy demand. Surplus wind energy from the Irish Republic will be a welcome addition to GB energy needs for Power to Gas. A strategy is thus required that maps out the demand for electricity network expansion and upscaling alongside the conversion and new-build of gas pipelines for green methane and hydrogen. This needs to include provision for bulk energy storage and decisions on their location. Respective work has already been reported (Samsatli 2019).

As mentioned, the number of hydrogen refuelling stations in the UK is tiny. There needs to be a willingness on the part of industry to build this infrastructure. An approx. five year investment lead is required for new infrastructure, before the end appliances arrive to use it, as can be shown for the mobile phone networks (Hardman 2015). Industry needs to be given confidence that there is a clear UK plan to develop and use the required infrastructure. Only such confidence will stimulate private investment, even if supported by public funding. Industry needs confidence that the regulatory framework will not change over a horizon of 20 years. It is therefore vitally important to build cross-party consensus on hydrogen policies, to avoid any major framework shifts once governments change. This will secure the stable private investment environment, including a long term perspective for industry. It is the role of industry to pay for infrastructure, not the taxpayer. The 'valley of death' faced by early infrastructure investors could be avoided by loans handed out or guaranteed by government.

Cost-benefit analysis of using hydrogen to meet Net Zero as well as the potential environmental impact of technologies required for its widespread use; and

Clearly, the environmental (external) costs of sustainable hydrogen-based energy economy will be far lower than with the current fossil technologies. This will not necessarily be the case for a net carbon zero scheme, as major costs are moved to future generations to carry. The environmental impact of any fossil fuel based energy supply remains remarkable, as Life Cycle Analysis shows.

As has been demonstrated in the White Paper on Energy Security published by the Supergen H2FC Hub in 2018, a hydrogen-based energy infrastructure would have many positive impacts on the resilience and robustness of the UK energy system. But the long-term advantages of energy independency will only be achievable if non-fossil energy sources are favoured within a plan for a sustainable energy economy.

Insofar the total societal cost of the energy system, that is the cost to the taxpayer and public health, including climate change and the impact of energy imports on national security, have to be compared between green hydrogen and fossil fuel based alternatives, including low carbon scenarios.

The relative advantages and disadvantages of hydrogen compared to other low carbon options (such as electrification or heat networks), the applications for which hydrogen should be prioritised and why, and how any uncertainty in the optimal technology should be managed.

Hydrogen could make a valuable contribution to meeting Net Zero, but it should be seen as just one piece of the puzzle. Decarbonising the supply of energy is important, but we should also be poised to substantially reduce the overall demand for energy. Though hydrogen is part of the future energy system solution, the importance of increasing energy efficiency cannot be overestimated. Electrification of energy services based on renewable electricity is another pathway to decarbonisation. Heat networks can be used for heat recycling and increasing overall energy conversion efficiency - experiences from Scandinavian countries in particular should be evaluated. Large scale home energy efficiency improvements and the support of heating networks by solar energy appear much more cost effective than the use of hydrogen. Nevertheless, hydrogen can play the role of seasonal energy storage, once residential heating demand has been dramatically cut.

Pursuing hydrogen as the 'silver bullet' solution will not allow the transition to a sustainable energy economy. All elements of a more sustainable energy supply system need to be exploited and included in the overall picture. There is no way government alone can decide on 'optimal' pathways. This can be left to the markets and end user preferences once the current energy price market failure(s) have been remedied. The same way petrol and diesel vehicles co-exist, many different ways of green hydrogen production, and end use of renewable energies in parallel to green hydrogen, green methane and other sustainable energy vectors, will co-exist. As some houses will allow for heat pump installation, others prefer (green) gas heating, it is not the role of government to prescribe this, but to oversee a level playing field market and eliminate all bias introduced by not charging real societal costs to energy suppliers.

First applications of green hydrogen should be directed at those energy sectors that are most polluting and where hydrogen can obtain the highest gain in energy conversion efficiency. The transport market clearly is one of those. The average fuel efficiency of an internal combustion engine road vehicle is no more than 20%. Turning these vehicles into electric drive with a hydrogen fuelled fuel cell as the energy source delivers clean transport with long range and rapid refuelling, thus supplying the same quality of transport services we have today at a dramatically reduced pollution level. It has to be kept in mind that substituting hydrogen for combustion fuels in hydrogen engines will neither increase the efficiency (rather in the contrary), nor reduce NOx emissions. Charging polluting vehicles, such as with the London ULEZ charges, can create the necessary level playing field that avoids public subsidies.

Other applications include the use of hydrogen in industry, not only by replacing fossil fuels, but also by supplying a base chemical to many types of industry.

In other areas, such as heating buildings, increasing the energy efficiency will be far more economical. The same is true for power generation, where green hydrogen will have a role in acting as a bulk (seasonal) storage commodity but not be a fuel for gas turbines or combustion engines due to the low roundtrip efficiency in these specific cases.

Hydrogen-fuelled vehicles are complimentary to rail electrification, and vehicles such as the HydroFLEX train retain their AC electrification equipment meaning that they can operate both on the electrified network and the non-electrified network. Network Rail's Traction Decarbonisation Network Strategy (TDNS) clearly articulates the need for hydrogen to be a vital part of the GB railway system. Therefore, the development and deployment of these vehicles is inevitable. It will be an interesting interplay between the eventual extent of the electrification which is required, and the performance and costs for the hydrogen vehicles. It is our expectation that rapid developments in the performance and capability of hydrogen vehicles could mean that we end up with a lower eventual electrification coverage than is anticipated by the TDNS in 2050. Electrification, battery and hydrogen, are complementary technologies, one viewpoint is that the rapid development of hydrogen will mean that the performance of the future hydrogen fuelled rail vehicles will mean ambition for such extensive electrification could in fact be reduced, and a decarbonised railway achieved well before 2050.

Summary of recommendations

- Pushing for a 100% zero-fossil-carbon economy by 2050 by reducing energy demand whilst building the renewable energy infrastructure will be by far the cheapest and fastest approach.
- The complete system of charging for grid services and the handling of the respective transport monopoly needs to be addressed in a holistic approach to creating level playing fields for energy in the UK.

- Charging the polluters for the full cost of extraction, distribution, and use of an energy carrier will create the competitiveness required whilst remedying the current market failure in energy carrier pricing.
- Hydrogen should also be linked to points 4, 5, 6 and 7 in the Ten-Point Plan. These are somewhat connected to hydrogen but this is not explicitly mentioned. All of these items require green hydrogen and hydrogen-derived fuels at the core of the solution.
- A government investment support programme of £50M to £100M is required to fund up to 250 hydrogen refuelling stations (HRS) in the UK.
- In order to do this, the UK needs to offer its own funding route comparable to the European funding. Dedicated agencies working closely with industry are required for the four nations. Ideally, these would coordinate general decarbonisation and energy efficiency measures in order to assure the 2050 goals are met.
- A matched investment to the £240M for net zero carbon hydrogen and £81M for hydrogen heating will be needed for green hydrogen developments, amounting to an additional £350M in order to achieve a zero environmental and societal balance sheet by 2050.
- The government has to commit to a stable and reliable commercial support and regulatory framework that will allow for long-term private investment to build the UK industry.
- Since a simple increase in fossil fuel prices will lead to a surge in energy poverty, a sustainable programme of support for improving energy efficiency has to be linked with respective increases in fossil energy prices.
- A well-designed market introduction scheme will be required to navigate the challenging issues of introducing hydrogen as a bulk commodity. Regulation will certainly be one way to address this.
- A strategy is required that maps out the demand for electricity network expansion and upscaling alongside the conversion and new-build of gas pipelines for green methane and hydrogen.
- It is vitally important to build cross-party consensus on hydrogen policies, to avoid any major framework shifts once governments change. This will secure the stable private investment environment, including a long term perspective for industry.
- Loans handed out or guaranteed by government could help avoid the 'valley of death' faced by early infrastructure investors.
- All elements of a more sustainable energy supply system need to be exploited and included in the overall picture. There is no way government alone can decide on 'optimal' pathways. This can be left to the markets and end user preferences once the current energy price market failure(s) have been remedied.
- It is not the role of government to prescribe ways of green hydrogen production, and end use of renewable energies, but rather to oversee a level playing field market and eliminate all bias introduced by not charging real societal costs to energy suppliers.
- First applications of green hydrogen should be directed at those energy sectors that are most polluting and where hydrogen can obtain the highest gain in energy conversion efficiency. The transport market clearly is one of those.
- Charging polluting vehicles, such as with the London ULEZ charges, can create the necessary level playing field that avoids public subsidies.

References

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