GREEN PAPER

The Geography of Hydrogen is the catalyst to economic stimulus and adaptation to climate change

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Stantec

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Foreword

The opportunity for hydrogen to play a major role in the decarbonisation of many aspects of our lives is rapidly emerging. As we see blue hydrogen emerging for industrial decarbonisation, the latest analyst predictions suggest that the cost of green hydrogen production from renewable electricity could be realised this decade and could then deliver at scale as we head to 2050.

To achieve this we need huge quantities of green electric generation to be deployed: but we also need significant quantities of water which could introduce challenges and knock-on impacts to other parts of society. Having worked in both the water and the gas sector, I appreciate the challenges this represents but believe we have an outstanding opportunity to rethink the interaction of electricity, water and hydrogen to maximise the opportunities that exist across the vectors.

This paper prepared by the team at Stantec tackles some of the fundamentals to think through where our resources exist, how they interact and how we might best deploy them for a resilient and efficient future. Net zero requires us to think more strategically, be more ambitious in our planning and above all deliver end-to-end solutions that minimise our overall impact on the planet.

Antony Green,
Hydrogen Director,
National Grid

A Summary of this Paper

Hydrogen is the smallest, lightest element and is present in the world's most abundant compound, water. With an energy density nearly three times that of petrol, the UK Government's Hydrogen Strategy[1] is planning for hydrogen to play a significant role in the decarbonisation of transport, heating, power generation and industry.

The scale of this swap could require in excess of 20 million tonnes of hydrogen which if green will need to be electrolysed from 330 million tonnes of fresh water, and an increase in UK electrical usage by nearly 330%.

The ability for the UK to establish hydrogen sovereignty will require a systems thinking approach, utilising transitional technologies such as blue hydrogen, as well as those emerging such as turquoise hydrogen[2].

The capacity for green hydrogen generation is defined by available water resources and access to renewable energy supply and associate infrastructure. Our analysis shows the UK has a fantastic potential for developing green hydrogen through FIVE green hydrogen clusters. This core production heartlands could be supported by a broad range of decentralised hydrogen manufacturing facilities which would provide the UK with energy resilience.

Deployment of green hydrogen infrastructure at scale will take time. Planning for transitional hydrogen generation technology will be needed.

Government will also need to pick priorities in use of hydrogen early or become reliant on a global supply chain—as we are with fossil fuels.

In addition, future pressures on water resources relating to climate change and population growth need to be considered now when planning infrastructure.

Water becomes a critical infrastructure in a hydrogen economy.

To reach the UK's hydrogen targets requires an understanding of our geography. Understanding the geographic factors of hydrogen will unlock whole systems thinking to deliver our infrastructure, encourage economic growth, and the 4th Industrial Energy Revolution. Hydrogen will reshape the UK's industrial economic landscape.

The UK Net Zero Strategy[3] sets out the need to take a systems think approach to delivering infrastructure.

In response to this we have considered the how the geography of natural resources defines spatial delivery of green hydrogen, the geographical relationship to demand and defined key stakeholders outside the energy sector that will underpin successful delivery of the economic opportunities that comes with the Government's Green Industrial Revolution.

In developing a spatial framework for hydrogen infrastructure, we have FIVE key recommendations for the public and private sector to engender whole system thinking and focus on critical parts of that system.

The UK Net Zero Strategy[3] sets out the need to take a systems think approach to delivering infrastructure.

Green Paper Recommendations

The study has shown a clear economic opportunity that delivers both social and environmental progress. Government will need to coordinate a number of economic pressures on UK resources—not least the increase in freshwater consumption and increase in national power generation—through National Infrastructure Planning.

It will require fiscal policy to stimulate private sector investment with long term returns similar to our statutory utility companies.

The study has shown Five Key Areas for Action to deliver the benefits:

1 There are a number of competing factors between how hydrogen will be used and where it will be generated. The UK Research and Innovation Council should direct resources to resolve uncertainty of use as this will significantly affect where hydrogen is generated.

2 Hydrogen is more than just new energy infrastructure. It has the capacity to enable levelling up, provide climate resilience in droughts, and underpin the future of movement. A cross party and ministry task force for hydrogen is needed to break the siloes in Department of Business, Energy and Industrial Strategy, Department for Transport, Department for Levelling Up, Housing and Communities.

3 The cross-sector nature of hydrogen will require its own planning policy.

A National Planning Statement for hydrogen generation and distribution is needed to safeguard all scales of hydrogen generation. Without strong planning support, the weight of hydrogen needed to decarbonise the UK cannot be delivered.

Local authorities will need to develop spatial planning for renewable energy, water resources and hydrogen generation. This will highlight new economic geographies that economically benefit from their physical geography in particular the North, Southwest, and Scotland. This will provide the evidence for levelling up investment and climate change mitigation.

4 Early private sector investment in hydrogen generation needs to think more strategically.

The location of generation assets must consider the geography of demand or they will become stranded assets in the future. Whilst national planning policy plays a role in the spatial planning of hydrogen, investors need to consider early the geography of the investments now to ensure they are not stranded in the future.

5 The role of water utility companies and the Environment Agency is critical as part of the hydrogen infrastructure system. This will create cross sector collaboration and competition to resolve water scarcity and hydrogen demand.

Background to this Paper

Understanding the geography of hydrogen will unlock whole systems thinking to deliver infrastructure, encourage economic growth, and the 4th Industrial Energy Revolution. Hydrogen will reshape the UK's industrial economic landscape.

The geography of all industrial revolutions has been defined by energy.

The first and second industrial revolutions were defined by coal shaping the UK industrial landscape in the Midlands and North, the third industrial revolution defined by the completion of the National Grid, distributing power to the South's economic dominance.

The 4th Industrial Energy Revolution is no different. It will see a seismic change in the forms of energy generation including nuclear fusion, small modular reactors, and national scale hydrogen generation, distribution, and demand.

The geography of these new energy forms will impact our entire economy, in the way coal and power distribution has done over the last 200 years.

The UK Hydrogen Strategy is looking to replace our current fossil fuel economy by retrofitting new hydrogen infrastructure into existing urban and industrial geographies.

The strategy silos generation, distribution and demand of hydrogen and puts the responsibility on the energy sector.

There is no consideration of the role of the water sector or hydrogen's relationship with levelling up and economic growth.

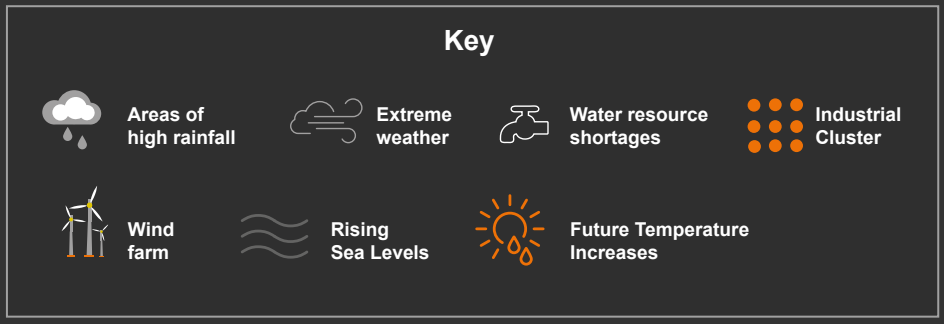
If, like all other industrial revolutions, the geography of energy influences economic growth, hydrogen will reshape the industrial economic landscape.

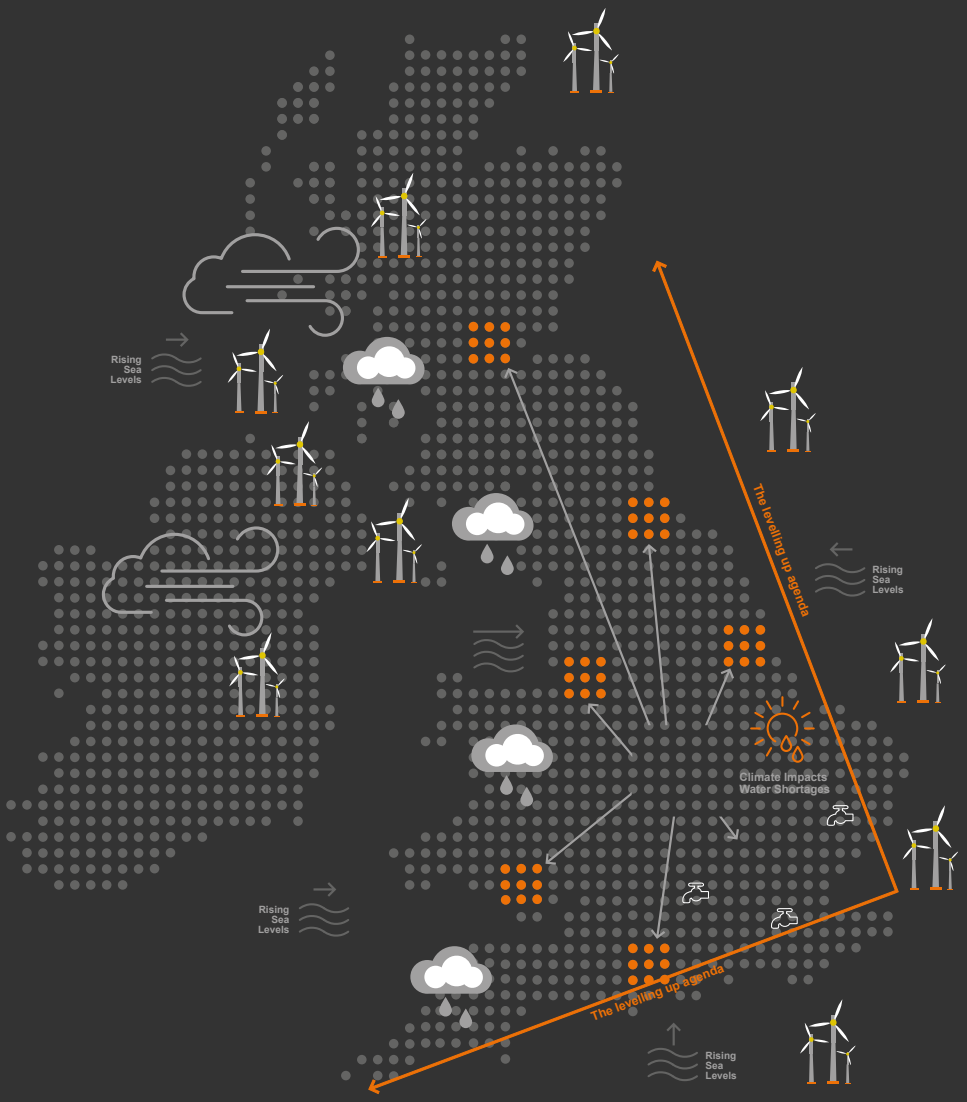
Understanding the geography of hydrogen will unlock whole systems thinking to deliver infrastructure and enable economic growth.

In response to this we have considered the how the geography of natural resources defines spatial delivery of green hydrogen, the ultimate end point to a fully decarbonised hydrogen supply chain. Like all other industrial revolutions we have looked at the geographical relationship between demand and generation. This has identified key stakeholders outside the energy sector that will underpin the economic opportunities that comes with the Government's Green Industrial Revolution.

If, like all other industrial revolutions, the geography of energy influences economic growth, hydrogen will reshape the industrial economic landscape.

The UK's geography provides some of Europe's greatest natural assets. The abundance of renewable energy and water in Scotland, the North, Southwest, and Wales provide the ingredients for the UK to be a powerhouse of hydrogen manufacturing. Combining this abundance, and the geographical locations of our future Industrial Clusters, hydrogen will be a stimulus for the UK economy.

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The levelling up agenda
The levelling up agenda

The geography of green hydrogen generation is influenced by renewable energy supply, water resources and synergistic infrastructure

The capacity for green hydrogen generation is defined by geography, available water resources and access to renewable energy supply and associate infrastructure.

When considering the use of hydrogen, we have to first consider the resources needed to generate it.

Water resource extraction for hydrogen will need to focus in areas where water is in abundance...

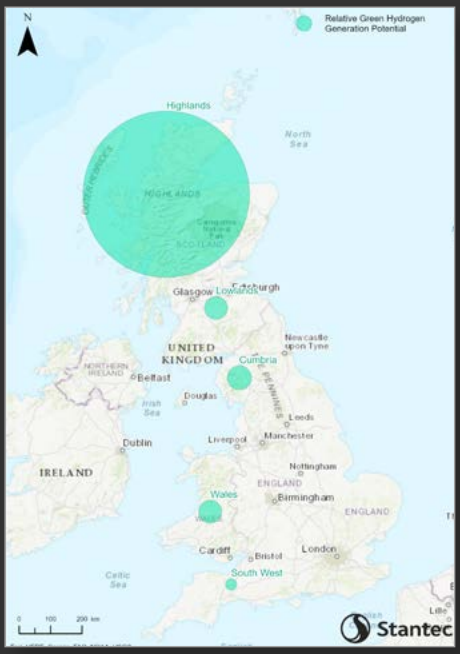
Green hydrogen generation is water intensive. Considering existing fresh water resource is critical for siting generation assets. If not considered early greater pressure will be placed on the competing water demands of industry , agriculture, ecosystems and population growth needs.

The UK extracts 10.4 billion tonnes a year[4] of water to meet our industrial, domestic and agricultural demands. These extraction rates place many regions in a water deficit, especially within our UK industrial clusters.

Water resource extraction for hydrogen will need to focus in areas where water is in abundance, namely Northwest England, Southwest England, Wales and Scotland.

An analysis has been undertaken of large water bodies across the UK in areas with a net positive water balance against power infrastructure and renewable energy capacity are defined into FIVE regional clusters that could collectively generation 2.3 million tonnes of hydrogen based on the geography of water resources and energy:

- **Highlands and Islands Cluster**
- **Central Scottish Belt**
- **Cumbria and Lancashire Clusters**
- **Welsh Clusters**
- **South West Cluster**



There is existing infrastructure in the UK that offer a spatial opportunity for hydrogen generation due to their existing or former use. The principal assets are coastal wastewater discharge, former power stations with ground water extraction consents, and nuclear facilities. Together these assets could form part of a network of decentralised hydrogen generation opportunities.

The analysis of sites suggests 19 former power station sites could produce 4.2 million tonnes of hydrogen per year. This could be supported by approximately 64 sites by a decentralised network generating an additional 50,000 tonnes of hydrogen. In addition, should by 2030 the UK maintain 6000MW of nuclear generation, there would be an additional potential for 1.2million tonnes of hydrogen[5].

How much hydrogen is needed to replace our fossil fuel use?

Approximately 9.7 million tonnes of hydrogen would be needed to completely replace the fossil fuel use of the UK haulage, aviation and industrial clusters. A green hydrogen approach would require a 150% increase in UK electrical supply.

Our industrial cluster energy demand uses 6,700 kilo tonnes of oil equivalent in energy a year.

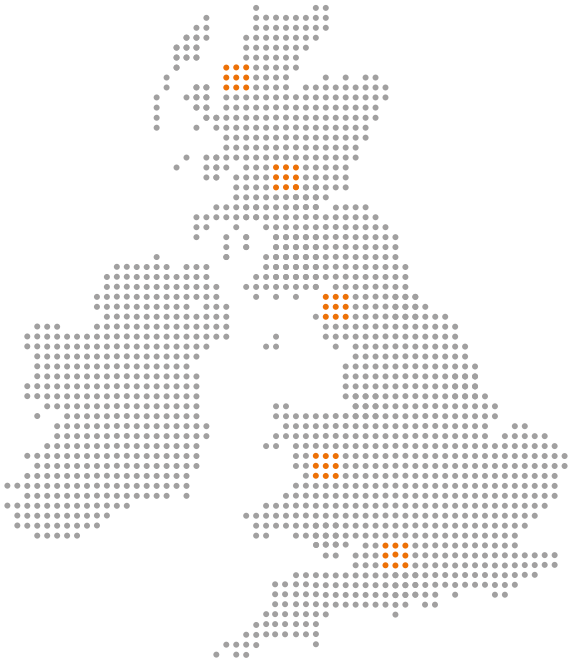
The UK Industrial Clusters could require 2.3 million tonnes of hydrogen consuming 39 million tonnes of water and 123TWh of electricity.

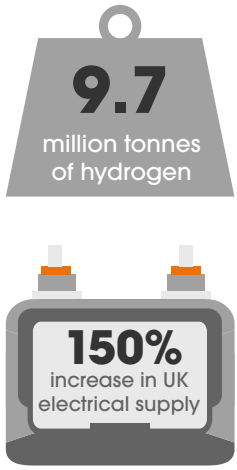
Our UK haulage sector uses 86.55GWh of fossil fuels.

The UK haulage sector could require 2.6 million tonnes of hydrogen consuming 44 million tonnes of water and 137TWh of electricity.

To put this into context, the UK's electricity consumption in 2020 was approximately 330TWh. The conversion of the UK industrial cluster and haulage energy consumption from fossil fuels to hydrogen would require approximate 75% increase in the UK electrical supply.

However, the UK Hydrogen Strategy does not stop there. It suggests that aviation and domestic heating will also be using hydrogen.



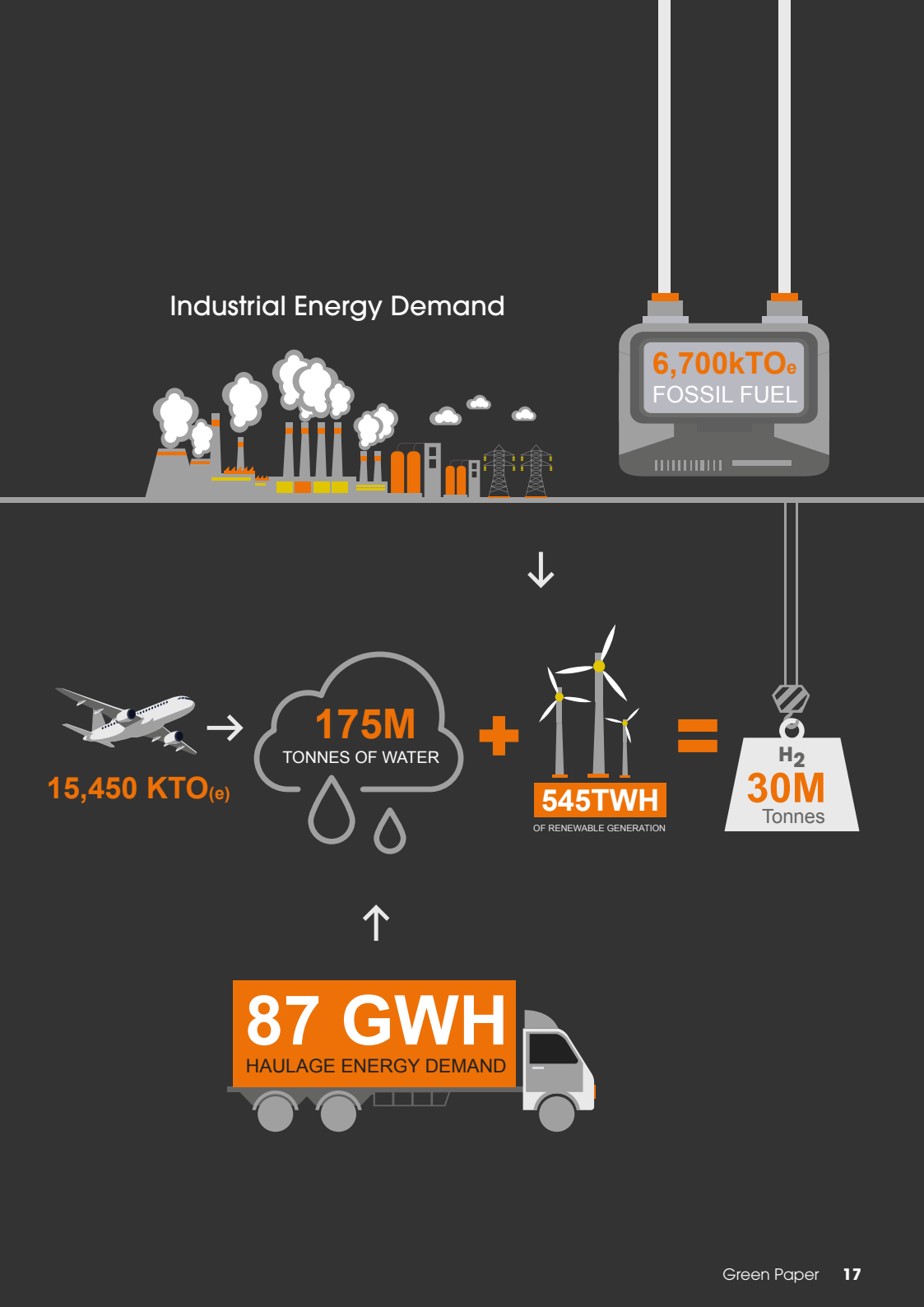


UK aviation sector could require an additional 5 million tonnes of hydrogen, consuming 92 million tonnes of water and 284TWh of electricity. The complete replacement of domestic gas with hydrogen would require a further 9 million tonnes of hydrogen.

Clearly renewable energy and water resource availability are critical to the UK hydrogen strategy against the location of the future demand.

The total equivalent in wind energy to meet the transport and industrial hydrogen demands would require over 7,350 new $14MW_6$ wind turbines i.e., 103GW of additional renewable capacity. This is within the expected doubling of the UK's existing renewable energy capacity to 110GW by 2030[7].

The conceptual model for demand and hydrogen generation sets the need for major investment in water and energy infrastructure across the UK to produce clean energy and fresh water.


Industrial Energy Demand
6,700kTOe
FOSSIL FUEL
15,450 KTO(e)
175M
TONNES OF WATER
545TWH
OF RENEWABLE GENERATION
H2
30M
Tonnes
87 GWH
HAULAGE ENERGY DEMAND

Planning the potential UK green hydrogen generation capacity

Water is a critical resource in a hydrogen economy. The geography of water resources will direct green hydrogen generation potential which may be limited by planning regulation ability to delivery hydrogen generation at scale. To avoid future hydrogen supply chain risks Government will need to pick priorities in use case early and invest in alternative hydrogen generation technologies.

It would require smarter integrated planning, reutilising brownfield sites such as former power stations, and links to water desalination investments.

The spatial analysis has shown that based on current water availability the UK has five regional clusters for hydrogen manufacturing.

Considering the protection of rural areas, it would require the industrialisation of parts of rural Scotland, Wales and the Southwest and Northwest of England and guarantees on the delivery of nuclear power.

This will require strong planning guidance from Government as these geographies are typically within high value landscapes protected from development. The planning system could be come the limiting factor in green hydrogen generation.

4 million tonnes of hydrogen could deliver the full decarbonisation of our UK industrial clusters and haulage transport.

To meet further demands the UK would need major investments in alternative carbon-based hydrogen generation.

The need for desalination infrastructure would require a re-think of renewables energy supply. With many water utility companies currently developing strategic operating reserves through the use of desalination, there is a major opportunity to twin investments in water and hydrogen generation. Especially when considering the only by-product of igniting hydrogen is water. Balancing water and hydrogen needs through combining storage will become part of the systems thinking of infrastructure delivery.

Research, innovation and investment should reflect this wider system thinking between sectors.

This system thinking needs to consider demands on power beyond hydrogen. The use of hydrogen and water infrastructure combined to resolve the increasing power burden of the electrification of transport and heating will be critical. All these new demands will increase the need for new energy storage.

Hydrogen as an energy and water storage vector is crucial to balancing these new burdens on the power networks.

This will also help define the need and direction of a national transmission network for hydrogen.

Spatial Framework for Hydrogen Network Infrastructure

National Grid has developed a spatial schematic of a backbone of national hydrogen infrastructure. The spatial schematic is based on potential import of hydrogen, links centres of hydrogen generation with existing energy infrastructure, hydrogen import potential and the UK Industrial Clusters.

This has been used as the baseline to extend to the areas of hydrogen generation identified, to produce a national schematic for hydrogen generation and distribution incorporating National Grid's backbone.

This plan takes into consideration the geography of industrial, aviation and haulage energy demands, synergistic infrastructure, and micro decentralised hydrogen generation opportunities.

More than just hydrogen infrastructure corridors

The purpose of developing a national hydrogen infrastructure needs to think beyond the siloes of Government departments.

Transported hydrogen could be converted back to water on ignition if captured from flue vapour. Water demands, especially in the south of the UK could become the driving demand for hydrogen, rather than energy.

The relationship between potable water, hydrogen energy storage, and future water resource needs should be explored in cross sector infrastructure decision making.

Currently the UK water sector is required to consider its future water provision, including planning for large scale 'inter catchment' water transfer and investments into desalination infrastructure within their SOR. Simply, transferring hydrogen as a vector for water would allow a single investment into a transmission network to meet two needs: decarbonation of energy, and water supply.

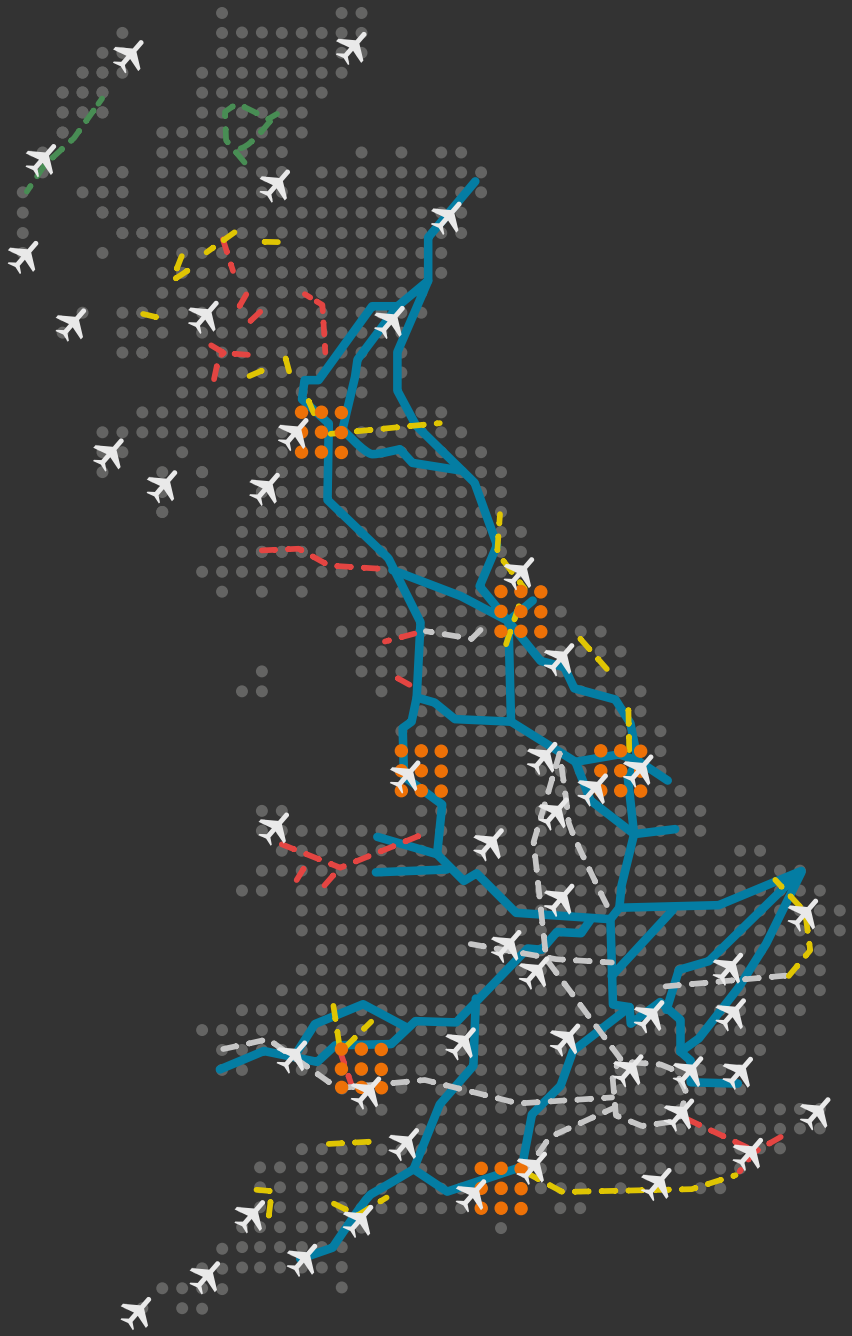
The transport sector is currently going through its own revolution. The future of autonomy in domestic travel and logistics changes the entire economic structure of how assets move. The hydrogen economy can provide the investment to underpin the industrial revolution in movement.

The hydrogen infrastructure corridors are therefore conduits to enable movement. Transport and hydrogen infrastructure should be combined into a single asset to enable this.

The hydrogen infrastructure corridors are therefore conduits to enable movement.

A UK hydrogen network map responds to the geography of generation and demand. Consideration of the future economic growth needs of the UK will direct zero carbon energy demand towards the resources.

The hydrogen network will create the economic stimulus for growth in the north and levelling up.



The Green Paper: Investing in the 4th Industrial Energy Revolution

There is a disconnect in the National Hydrogen Strategy between the wish for multisector decarbonisation and the reality of available resources. In developing a spatial framework for hydrogen infrastructure, we have FIVE key recommendations for the public and private sector to engender whole system thinking and focus on critical parts of that system.

1 **There are a number of competing factors between how hydrogen will be used and where it will be generated.** The UK Research and Innovation Council should direct resources to resolve uncertainty of use as this will significantly affect where hydrogen is generated.

Unlike fossil fuels, hydrogen has to be created. The UK has abundance of natural energy and water resources, which offers the UK hydrogen sovereignty.

This will require Government to prioritises use cases as they have noted in the Net Zero Strategy with a decision in 2026 for the use of hydrogen in domestic heating.

Until such time as green hydrogen production has become efficient in energy use, the need for transitionary hydrogen technologies will be critical to meet demand. The full spectrum of hydrogen generation will be require support the energy transition.

Research and innovation needs to bring the disconnect together. Focus on use case creation before technology will be critical to ensure investment in hydrogen is not wasted on who shouts the loudest.

In addition research and innovation needs to support transitionary approach to hydrogen generation to enable demands to be met early.

2 **A cross ministry task force for hydrogen is needed to break the siloes in BEIS, OFGEM, OFWAT, OFCOM, DfT, and DLUHC to create a coalition for change.**

The pace of innovation defines the 4th Industrial Revolution. As with all industrial revolutions, this pace fundamentally changes society and government.

In the same way coal dictated society and government 300 years ago, hydrogen will do the same now.

The delivery of the 4th Industrial Revolution is defined by systems thinking. This requires cross sector coordination by both the private sector and government.

Government therefore needs to be ready to deal with the pace of the success of the UK Hydrogen Strategy.

This will require cross ministerial strategy and ownership to capitalise on the national scale infrastructure investment in water, electricity, data, and transport.

A mind set change is also needed by the private sector. Whilst planning policy is developed for our hydrogen economy investors have to think beyond short term returns without any spatial consideration to demands.

3

The cross-sector nature of hydrogen will require its own planning policy and regulation.

Like all previous industrial revolutions, this revolution will need to consider the hyper industrialisation rural Britain.

We have seen with renewable energy development that localism stymied delivery in England and Wales but was embraced in Scotland.

The UK cannot expect to deliver the weight of hydrogen needed to meet demand without clear guidance and justification in the planning regime.

To meet our targets, both national infrastructure projects will be needed through development consent orders. A far greater number of facilities will need to be delivered through the Town and Country Planning Act.

The delivering of our hydrogen generation needs will be in jeopardy without planning policy, to ensure a comprehensive transition of fossil fuel demand to hydrogen.

A National Planning Statement for hydrogen generation and distribution is needed to ensure all scales of hydrogen generation are safe guarded. Without strong planning support, the weight of hydrogen needed to decarbonise the UK cannot be delivered.

Local authorities will need to develop spatial planning for renewable energy, water resources and hydrogen generation. This will highlight new economic geographies that economically benefit from their physical geography in particular the North, Southwest, and Scotland. This will provide the evidence for levelling up investment and climate change mitigation.

With water being a primary asset in hydrogen generation and as a by-product of combustion the Environment Agency and DEFRA are critical agencies in policy creation and regulation.

4 **Private sector investment needs to think strategically now in locating hydrogen generation. They should consider the geography of demand and engage early with utility companies looking to invest in hydrogen networks. This will avoid stranded assets in long run.**

Economic geographies or sectors with direct supply of cheap and secure hydrogen will prosper. Geographies and sectors that are reliant on imports of hydrogen will be exposed to competition and supply pressures.

As with all industrial revolutions, economic prosperity defined economic and population growth.

The Northern, Southwest, and Scottish economic geographies will flourish due to their abundance of water and energy.

This will include their industrial economies that will out compete the existing industrial economies defined by the legacy of fossil fuel.

The private sector need to invest to make this happen.

Coupled with the pressures of climate change in the south of Britain, the home for Industry 4.0 needs backing where resources can deliver it.

This will reshape the UK population distribution.

5 **Hydrogen needs to be seen as a utility that can benefit water companies strategic operating reserves. Balancing water resources and energy storage will create cross sector collaboration and competition to create water and energy security of supply for all**

Currently the UK Hydrogen Strategy focuses on demand, generation and distribution without regard for other infrastructure in particular the transport and water.

The provision of a hydrogen network will alter the geography of movement. The existing geography of aviation and logistics, for example, is backed by fossil fuel infrastructure.

Prior to replacing fossil fuel infrastructure with hydrogen Government has a unique opportunity to influence movement across the UK. Future economic models for movement such as Movement as a Service will change the point demand for fuels. Technologies such as autonomous movement can be provided by a completely different energy infrastructure provision. The UK needs to design infrastructure to how we will use energy in the future, not how we used fossil fuels in the past.

Similarly, the statutory water companies are being asked to develop their Strategic Operating Reserves in the face of climate change. If the UK Hydrogen Strategy is looking to distribute across the UK, then the water created by this distribution network should be factored into the water companies' planning.

Notes from the editor

The UK's physical geography defines its economic geography. For this industrial revolution, the physical impacts of climate change are a significant variable to defining our economic geography.

This analysis has looked to address the shortfalls in the UK Hydrogen Strategy. It has set out a geospatial appraisal of the UK's natural resources and infrastructure needed to generate hydrogen. It has attempted to quantify the green hydrogen generation potential, the geography of energy demand relating to transport and industrial use, and the UK's strategic water resource needs.

A whole environmental, social and economic system thinking approach has been taken based on future needs, and not past demands.

The physical geography of the UK represents the greatest combined renewable and water resource assets in Europe.

The existing industrial geography is driven by our island's exports and imports and our need to import fossil fuels. Our energy demand is underpinned by the national transmission network, supplied by an ever-increasing offshore renewable potential and nuclear energy supply.

In establishing the whole system thinking for hydrogen, we have considered how this infrastructure framework will create a catalyst for the economic opportunities that comes with the Government's Green Industrial Revolution[8].

The paper has shown that the delivery of hydrogen infrastructure requires more consideration across ministries than just BEIS alone. Government is not alone in the need to think beyond its own operational remits.

To ensure a successful economic future both the private and public sector need to truly understand what system thinking means within their role in Building Back Greener.

The physical geography of the UK represents the greatest combined renewable and water resource assets in Europe.

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