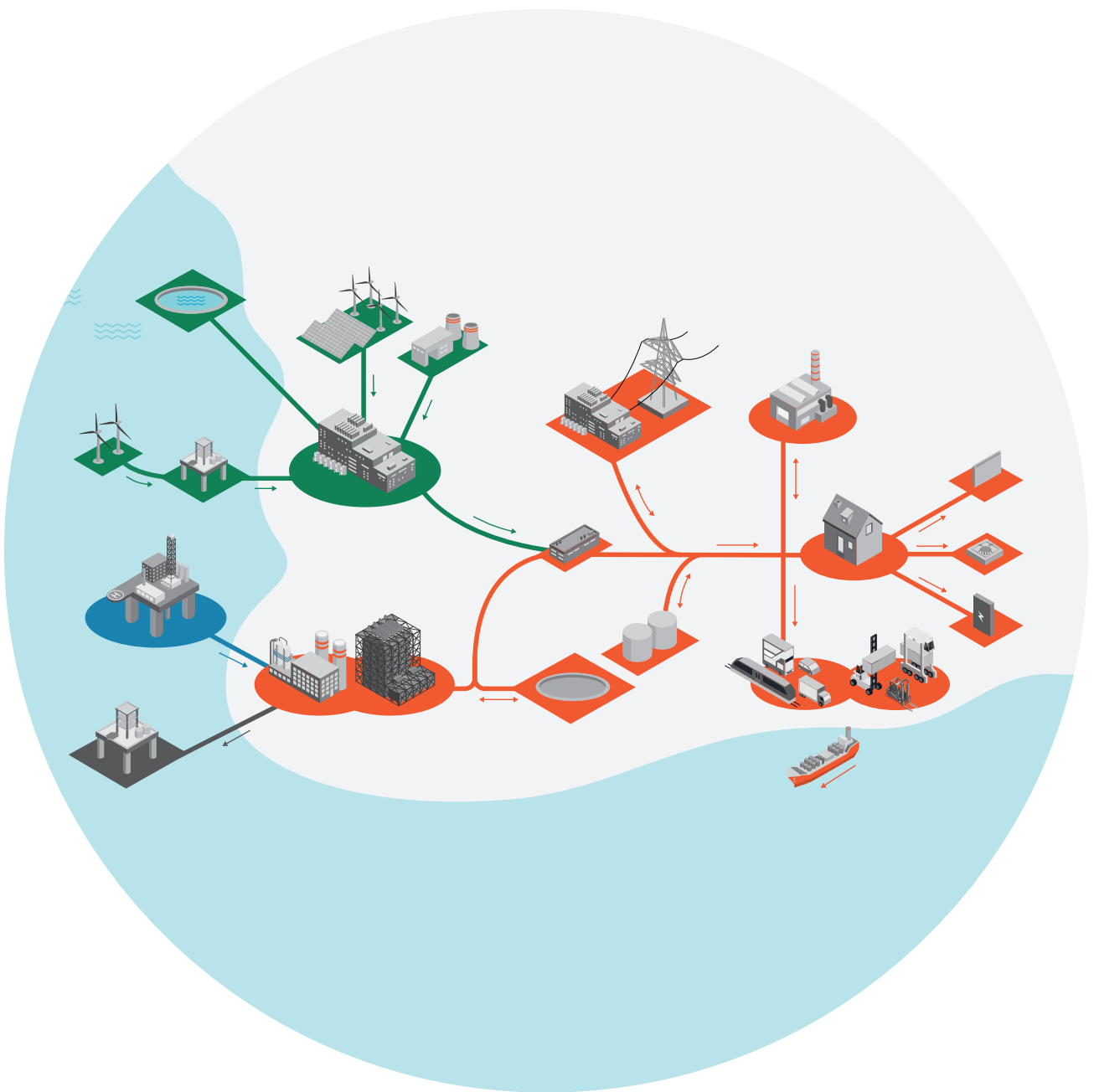


Establishing a Hydrogen Economy

The Future of Energy 2035

United Kingdom and the Netherlands



The establishment of a strong hydrogen economy is a very real opportunity and within reaching distance. Private sector investment, facilitated by appropriate government policy will allow countries to benefit from significant decarbonisation across the entire energy system. A hydrogen economy could be a major differentiator for local energy, transport and industrial sectors with substantial export potential.

Encouraging a future hydrogen economy

Both the Netherlands and the United Kingdom have a significant opportunity to decarbonise their energy system and act as a role model for countries looking at low carbon pathways. Following on from Arup's thought-provoking report, 'Energy Systems: A view from 2035', it is clear there is a pivotal role for hydrogen in the energy market of tomorrow.

This report explores the future of the hydrogen economy and lays out a series of action point. The insights captured here are the result of extensive consultations and workshops Arup has carried out across the UK with industry players, academics, and other key stakeholders. This work advances a much needed conversation on how best to take advantage of the opportunities presented by the hydrogen economy; the utilisation of hydrogen as an important energy store and vector.

Hydrogen doesn't come without challenges. There are many hurdles to overcome before we see the development of hydrogen at scale, but the potential benefits greatly outweigh the challenges. It is difficult to see how countries such as the United Kingdom and the Netherlands can achieve a secure, resilient and decarbonised energy system, able to balance supply and demand, without a substantial role for hydrogen.

Building resilient infrastructure also requires having the right policies in place to secure the capital investment needed to create a successful hydrogen economy. Arup's report rightly highlights the progress already being made in utilising hydrogen for transport and heat, albeit in small pockets.

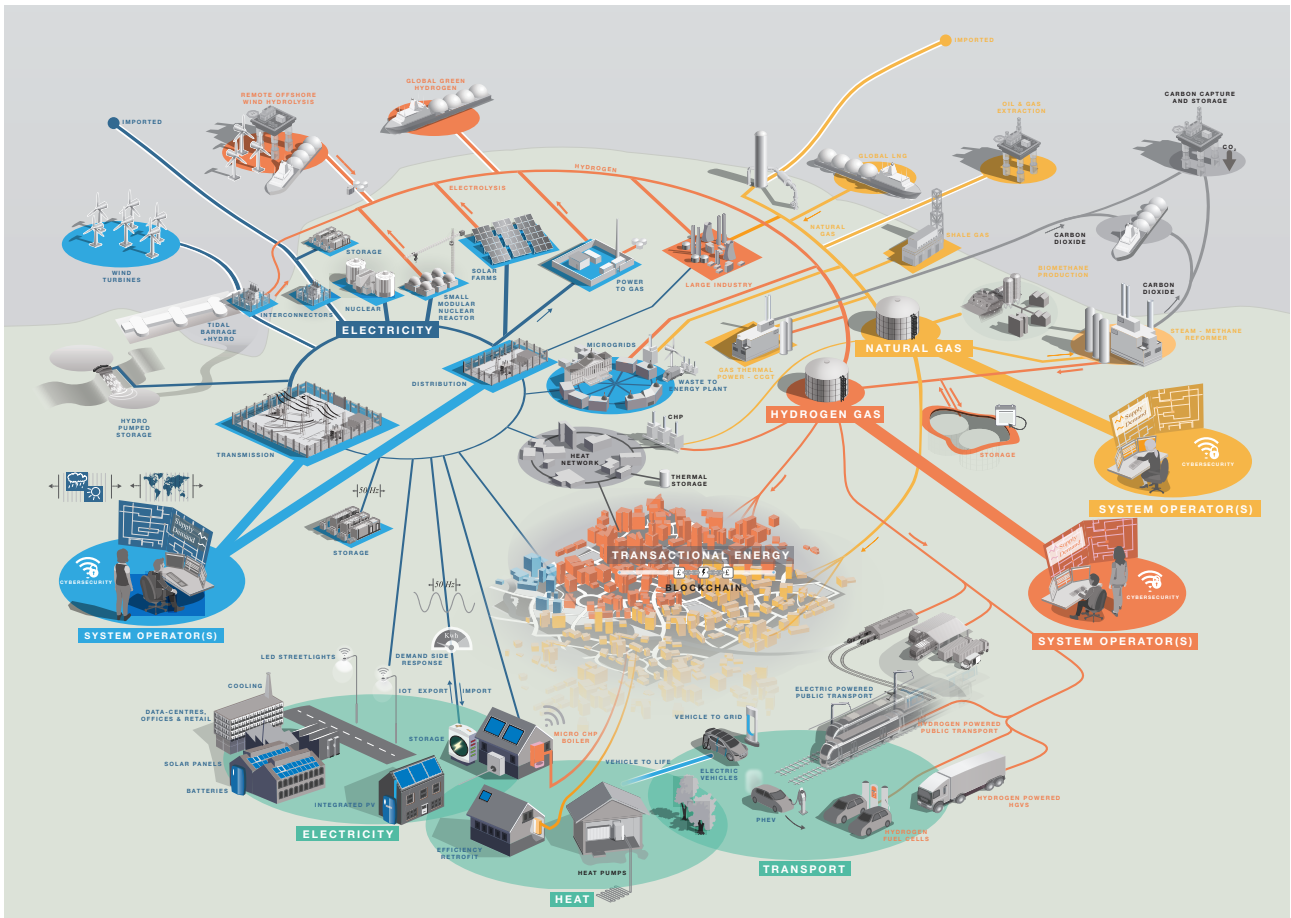
However, further policy progress will require even closer collaboration between academia, the private sector and other stakeholders to shape future demand, change consumer perception and create the strong supply chains needed to allow the hydrogen economy to thrive.

This in turn will boost affordability and create numerous job opportunities for years to come – benefits that can be shared by all.

Hydrogen has great potential to be the catalyst for decarbonising the local energy system and with the work of Arup and others, we can transform this aspiration into reality. We need to see rapid progress in the coming years to meet our legally binding emission targets, and this report provides a roadmap to show that we all have a role to play on this journey.



Keith MacLean
UKERC Board Member



Arup's 'Future of Energy 2035' map
showing the energy system of the future

The essential hydrogen economy

Arup has undertaken significant work to explore what the future energy system could look like through the transition to 2050. Our findings have identified hydrogen as an integral part of the future system to assist in decarbonisation.

With hydrogen gaining traction in a number of countries across the world including the UK, the Netherlands, New Zealand and Japan, this report explores how we are on the cusp of a hydrogen economy.

A future perspective

Arup undertook a series of workshops with public and private sector organisations involved or interested in hydrogen - from government and across a section of the supply chain. In an emerging and immature market, our facilitated workshops helped industry explore the challenges and opportunities. This perspective explores the findings and the next steps to ensure a viable hydrogen economy.

A case study

This report includes a case study and outlines how hydrogen will be a credible and prominent feature to a 2035 energy system model.

The current market

In recent years considerable progress has been made within the hydrogen industry across production, transportation and use, including:

- Large scale green hydrogen production (electrolyser) feasibility studies including downstream hydrogen applications in harbour areas (HEAVENN - Groningen, H2ERMES-Amsterdam)
- Blue hydrogen feasibility studies in which the CO₂ released during production of hydrogen out of natural gas is stored in empty offshore gas fields in combination with

CO₂ infrastructure (H-vision- harbour of Rotterdam, Athos - harbour of Amsterdam)

- Hydrogen infrastructure: natural gas pipeline between Yara and Dow Chemical has been transformed by Gasunie to hydrogen pipeline.
 - Residential hydrogen applications, heating in for example Hoogenveen and Haringvliet
- Transport sector using buses, fleet vehicles and a hydrogen-powered train in Groningen

Ongoing research

There are many research and feasibility projects underway, largely funded by government bodies and the gas distribution companies. These are looking at a diverse range of issues including safety, technical feasibility, economics and consumer acceptance.

There appears to be little need for new technology as at a component level, much of this already exists. It is the co-ordination between government and industry players that is the key challenge that needs to be overcome.

It's clear there is still work to be done before hydrogen can fulfil its potential as a key enabler in decarbonising the energy system.

Hydrogen Economy 2035

By 2035, hydrogen could already be playing an important role in decarbonising energy systems.

Our graphic demonstrates the different methods for producing low carbon hydrogen, as well as the opportunities for using the energy once it is created.



Hydrogen creation

Electrolysis via renewables is a method in which electricity splits water into hydrogen and oxygen. The hydrogen can then be stored, and the oxygen can be released into the air or stored.



Reformation from methane is another way of producing hydrogen. Carbon capture storage (CCS) technology can capture the carbon dioxide that is produced from the process.

Hydrogen usage



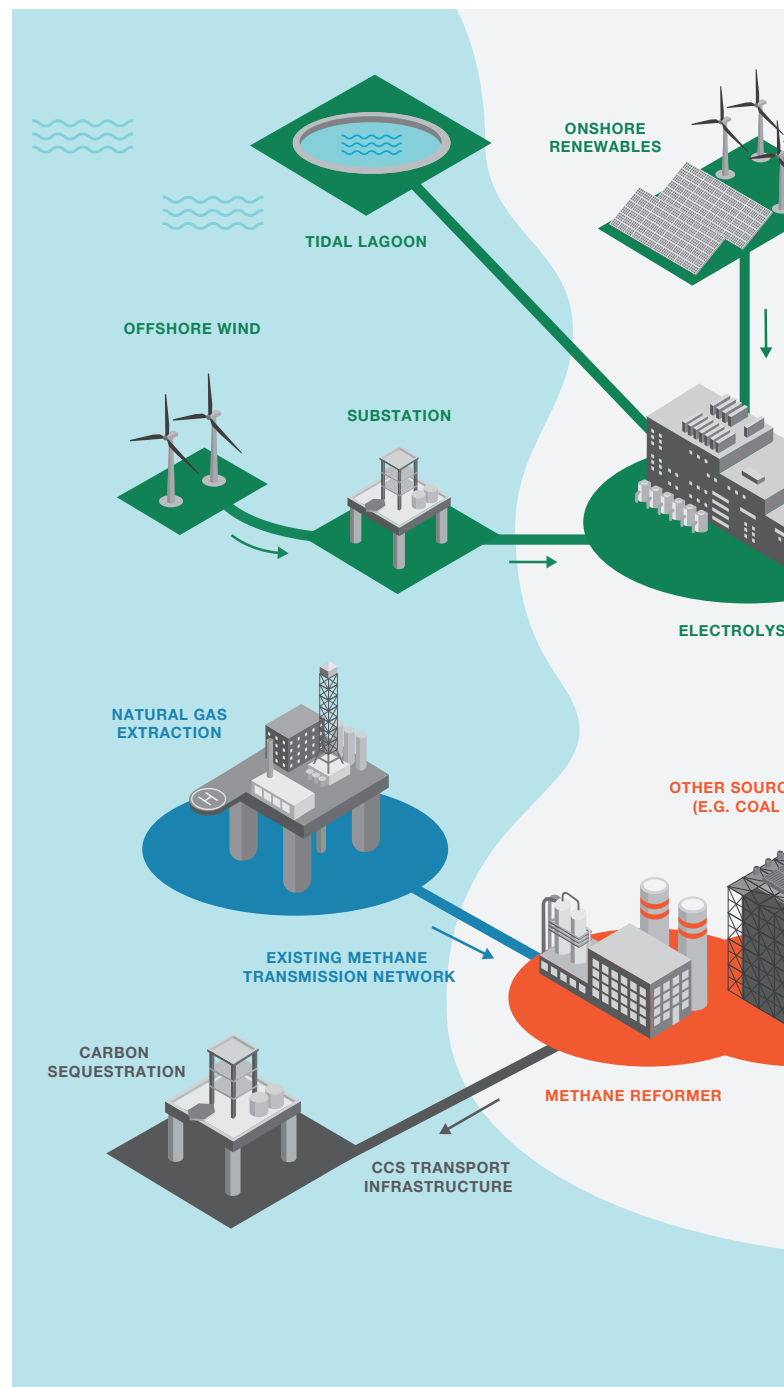
Transport: Improved fuel cell technology for buses, trains and ferries demonstrating hydrogen use where its rapid refuelling time and higher efficiency density give it an advantage over batteries.

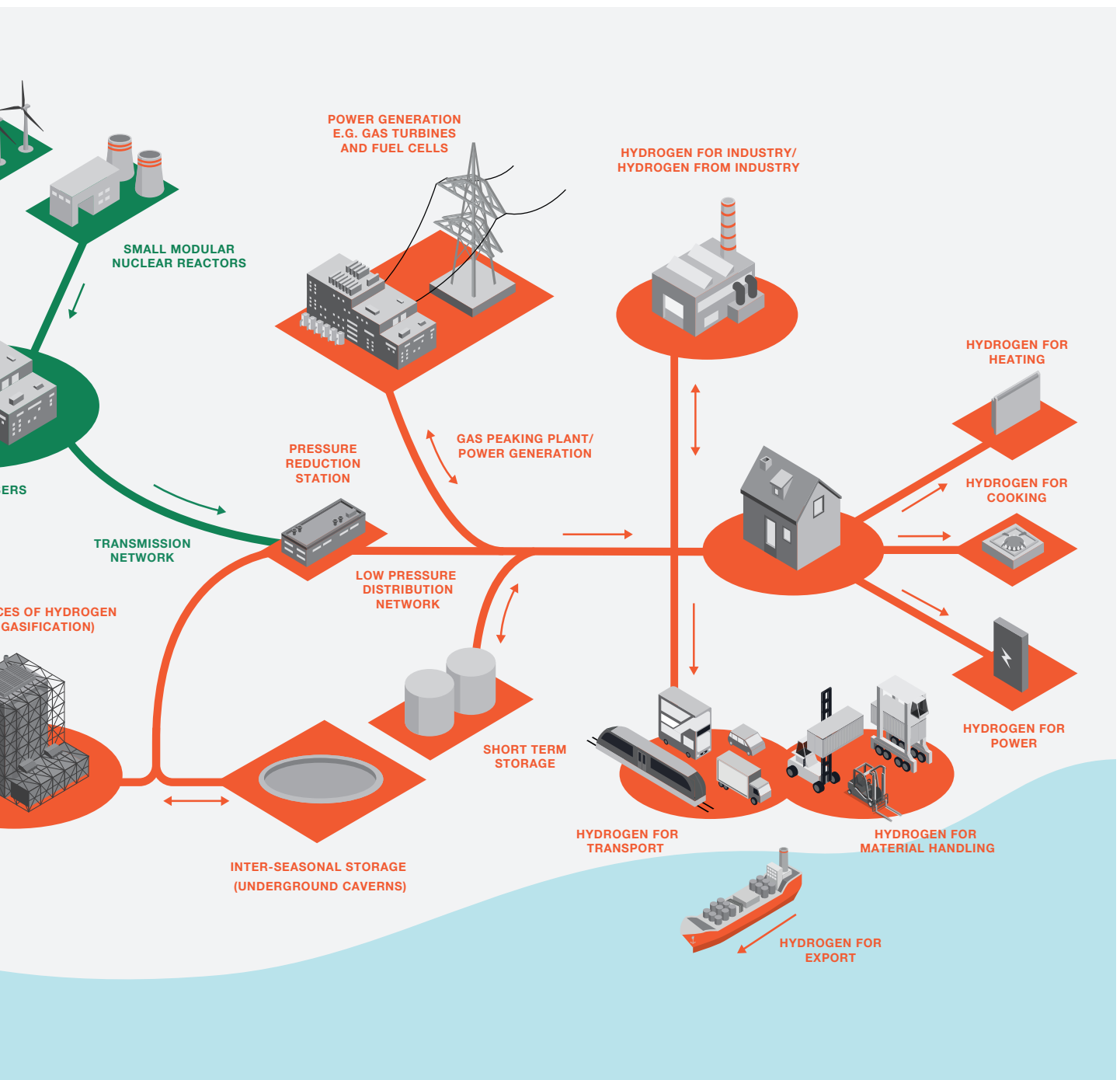


Industry: Heavy industry, for example glassmaking and pottery, use high temperature furnaces that emit large volumes of CO₂. A move to hydrogen offers a big opportunity to decarbonise. Steel making also has the potential to export hydrogen to the grid, as a by-product of the production process.



Homes: Using existing gas infrastructure hydrogen could provide a safe and reliable source of energy for heating, lighting and appliances, where retrofit for electrification could prove costly.





What are the challenges the hydrogen economy needs to overcome to succeed?

Governments need to overcome numerous challenges over the coming years to allow organisations, industry bodies and individuals to feel confident in investing in the hydrogen economy supply chain.

Attracting demand

Without growing demand, the large-scale production of hydrogen will not happen. This demand could come from a number of sources, all of which require a broad range of end user appliances and equipment that is standardised, desirable, safe and affordable. However, without a strong supply chain which acts to reduce the costs of hydrogen, and provide confidence in the capability of industry to deliver a secure and affordable fuel, consumers and public and private sector buyers will be reluctant to purchase hydrogen products.

This is the dilemma that needs to be addressed: how to incrementally build demand and supply in the most cost-effective manner.

Enabling infrastructure and investment

Hydrogen requires infrastructure to get it from source to end user. The capital investment needed is significant and reliant on long term indication and forecasts. If new business models and new tariff arrangements are to emerge and thrive, policy-makers need to establish a robust, credible and flexible framework. This may not necessarily take the form of the traditional regulated network model. Especially if it is based on a modular approach that increases network size and applications over time, as demand for hydrogen grows incrementally on a regional or market basis.

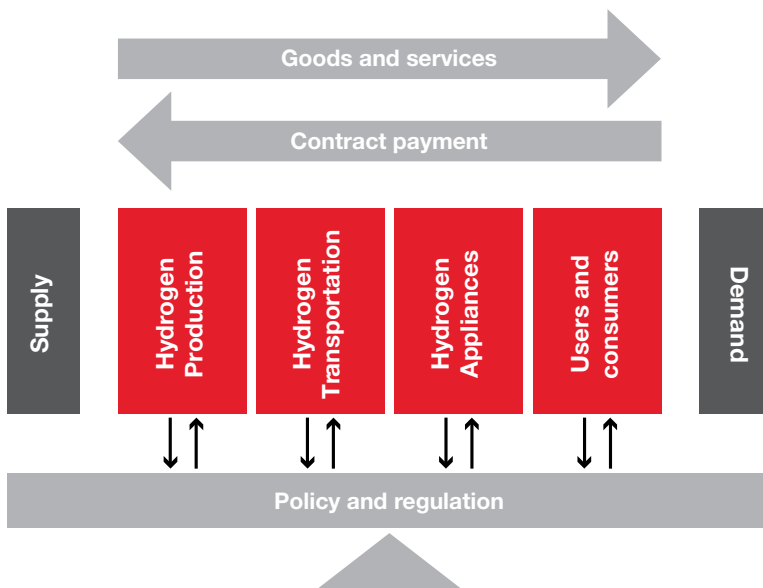
The end goal is to have a sustainable hydrogen economy with both the production and infrastructure in place and importantly - a demand from end users.

One approach to policy

Government has an essential role to play for hydrogen to establish its place in energy systems. Policymakers have both the opportunity to stimulate demand and the tools to ensure hydrogen is able to compete on a level playing field with other decarbonisation pathways. The challenge for government is to establish how it can most effectively stimulate the hydrogen economy, both for the established energy players and disruptive market entrances. The challenge for the industry is to speak to government with one voice about what is needed.

Ultimately it is consumer demand that will support and sustain the business case for a future hydrogen economy. The perception of hydrogen must change so it is seen as a trusted alternative to current fuels and as a means to decarbonise. A strong narrative is required around how hydrogen can deliver benefits to consumers and value to investors. It is about providing consumers a choice and allowing the transition from one fuel source to another fuel source. Continuing to bring together key players in collaborative way will help push the cause further.

Raising the awareness about the challenges the different parties face, identifying solutions and establishing relationships across the supply chain and government is an essential next step.



How to achieve the hydrogen economy

A clear road map and vision should be established to make the hydrogen economy achievable. Below are some key considerations which can help the industry overcome the challenges and grasp the hydrogen opportunity.

These focus areas have been a discussion point throughout the public and private sectors from transport to large scale consumer. Some are short term achievements whilst others are long term initiatives, but all essential to a successful decarbonised energy system.

One thing is certain - action needs to start now.



Bring consumers along

Consumers are at the centre of the hydrogen economy - they will drive demand for hydrogen through their purchasing choices.

Effective communication with consumers needs to be clear around the requirements to change their behaviour to assist in decarbonising transport and heat and use alternative energy sources. It's important there's recognition that remaining with the status quo is not an option as it will lead to missing the legally binding Climate Change Act targets, higher costs in the longer term and a burden to future generations.

Consumer confidence is built incrementally, with safety concerns addressed over time, in a planned and strategic way; however, there is urgency to start now. The benefits associated with hydrogen need to be communicated in such a way that is beneficial to consumers.

We need to highlight air quality improvements, reduced noise and greater range extension on electric vehicles. As part of this we also need to focus on education, inspiring the younger generation about a cleaner future and upskilling the industry.



Quick wins

Focus should be on delivering high profile projects quickly, such as hydrogen use in transport - in particular public transport and return-to-base fleets. This will build confidence, experience and a supply chain needed to tackle more complex challenges such as using hydrogen for heating. Utilising otherwise wasted surplus hydrogen - including banning flaring – could be a significant step for the industry.

Building on the good work already underway to demonstrate hydrogen as a community solution, particularly where renewable energy is constrained. These examples should be used as good models to support further roll out.

The limits placed on how bills are calculated and the type of gas used in the network requires expensive interventions and limits the introduction of other gases such as hydrogen. Changing this is a no regrets step to blending hydrogen into the network.

Government should explore implementing policy design to stimulate investment and lead to a levelling of the playing field, given the high levels of government support for other low carbon technologies. It is important to seek parallels and lessons from other transitions, where new technologies and industries have been successfully developed and emissions reduced, following policy interventions.

One way to do this is to place an obligation on energy companies to supply increasing amounts of decarbonised gas, such as hydrogen, in much the same way that has been done for renewable electricity.



Into the future

There should be a focus on stimulating demand in stages. First around transport and heavy industrial processes. This would be followed closely by blending in the gas network, before we can consider a move to 100% hydrogen for heat.

Ports and ferries are areas where uptake of hydrogen solutions will have air quality improvements and a range of benefits over purely battery alternatives.

Heavy industrial processes provide an ideal anchor for hydrogen projects. The construction of a number of regional hubs, supplying hydrogen to meet industrial demand, and blending surplus into the gas network would deliver substantial carbon savings. Gradually increasing the proportion of hydrogen, up to 20%, the point at which current domestic applications can still work, will support the incremental build-up of the capacity and capability to produce hydrogen.

Investments can therefore be incremental, with a reduced risk profile. It will lead to a gradual reduction in the cost of hydrogen for all applications, and prepare for a possible future conversion to a 100% hydrogen gas network.

Hydrogen is not an all or nothing approach. The hydrogen economy isn't entirely dependent on the outcome of 100% hydrogen for heating. The case for hydrogen in transport, industry, as a blended fuel, and storage medium is sufficient to stand alone.

What happens next?

Having explored the challenges and opportunities, what needs to happen for the UK and the Netherlands to establish a leading position, it is clear there is urgent need for action.

Government policies are needed in the imminent future to establish a robust supply chain, encourage new business models and inject investment into infrastructure. It's all possible and achievable to reach emission and climate change targets. Below are some final thoughts to consider about the potential of hydrogen.

The future of hydrogen is here

- *Pilots and at scale demonstrations* – to support the development of policy, business cases, technology, consumer confidence and build supply chain capacity.
- *Public understanding* – a shift in the public perception of ‘energy’ as just electricity, the need to decarbonise the entire energy system and promote the role hydrogen could play.
- *Coordinated research* – a centrally coordinated group from across academia and industry to determine knowledge gaps and agree a portfolio of evidence gathering research.
- *Learn from overseas* – there are opportunities to learn and build on best practice from across the world, from advanced blending to repurposing transmission pipelines.
- *Policy and market design* – government and industries must work together to develop innovative market structures that provide value for money for tax payers and offer options to de-risk for the industry.
- *Jobs and employment* – the hydrogen economy offers a fantastic opportunity to support high quality jobs which will require highly skilled and trained workers, as well as export opportunities in a growing international market.

Hydrogen in conjunction with other technologies represents a significant opportunity to decarbonise the energy system and generate jobs.

Acting now will enable the UK and the Netherlands to take leading roles for the benefit of industries and the population.

Special thanks to all those who participated in various hydrogen workshops to explore these issues.



Applying our Hydrogen expertise

Arup works on behalf of a broad range of clients from governments to energy network owners, each with different objectives and challenges. Our work across the Hydrogen market helps clients to meet their strategic and delivery programme objectives - from business case and investability to technology development and safe deployment. Our broad expertise means we can deliver outcomes along the Hydrogen chain.

Hydrogen System Modelling

We can support by:

- Modelling green and blue Hydrogen production, transshipment and end use scenarios, including transport and heat
- Hydrogen chain efficiency loss evaluation in various scenarios
- Integrated energy system analysis



Strategy and Policy Advice

we can support by:

- Developing clear strategies that enable Hydrogen ecosystem to be developed at an international, national, regional and local level
- Evaluating the practical techno-economic opportunity and solutions afforded by Hydrogen
- Articulating the most effective complementary combination of Hydrogen energy supply with electrical and other means
- Developing Hydrogen deployment roadmaps leading towards net zero



Financial and Business Case Expertise

we can support by:

- Developing business models for infrastructure roll out and operation
- Undertaking market studies and econometric analysis for different Hydrogen use cases
- Building out revenue and costs through full financial modelling
- Supporting applications for private investment, multilateral bank or central government funding
- Costing of Hydrogen infrastructure, installations, connections and upgrades



Feasibility Studies

we can support by:

- Managing and running feasibility studies for Hydrogen deployment, including production, transshipment, storage and end use
- Undertaking site feasibility studies and advising on site selection
- Appraising potential of wind, solar or Hydrogen storage
- Developing environmental impact assessments and strategic environmental assessments
- Developing and supporting planning applications

Implementation

we can support by:

- End to end management and planning of Hydrogen programmes and projects from strategy through to implementation
- Managing schedule and commercial risk
- Undertaking operational readiness assessment

Safety and Risk Analysis & Design

we can support by:

- Managing and undertaking strategic safety assessments and commissioning advanced safety research
- Developing national and local regulatory requirements for Hydrogen deployment
- Detailed technical safety and risk evaluation, including HAZID and HAZOP



Technology Appraisal

we can support by:

- Undertaking technology appraisal focused on heat, mobility and feedstock use
- Analysing capex and opex cost declination and functionality improvements
- Specification, market testing, supply chain engagement and procurement of Hydrogen equipment and infrastructure



Human Factors and Stakeholder Engagement

we can support by:

- Engagement with key stakeholder groups, demonstrating the features of Hydrogen in a well informed accessible manner
- Undertaking Hydrogen demonstration trials and road-shows
- Developing live community trials and demonstrator projects
- Capturing and communicating emerging contemporary knowledge to stakeholder groups, addressing concerns and reinforcing benefits of Hydrogen



Our previous experience

Port of Auckland Green Hydrogen

We are delivering New Zealand's first Hydrogen hub, decarbonising port and wider city transport.

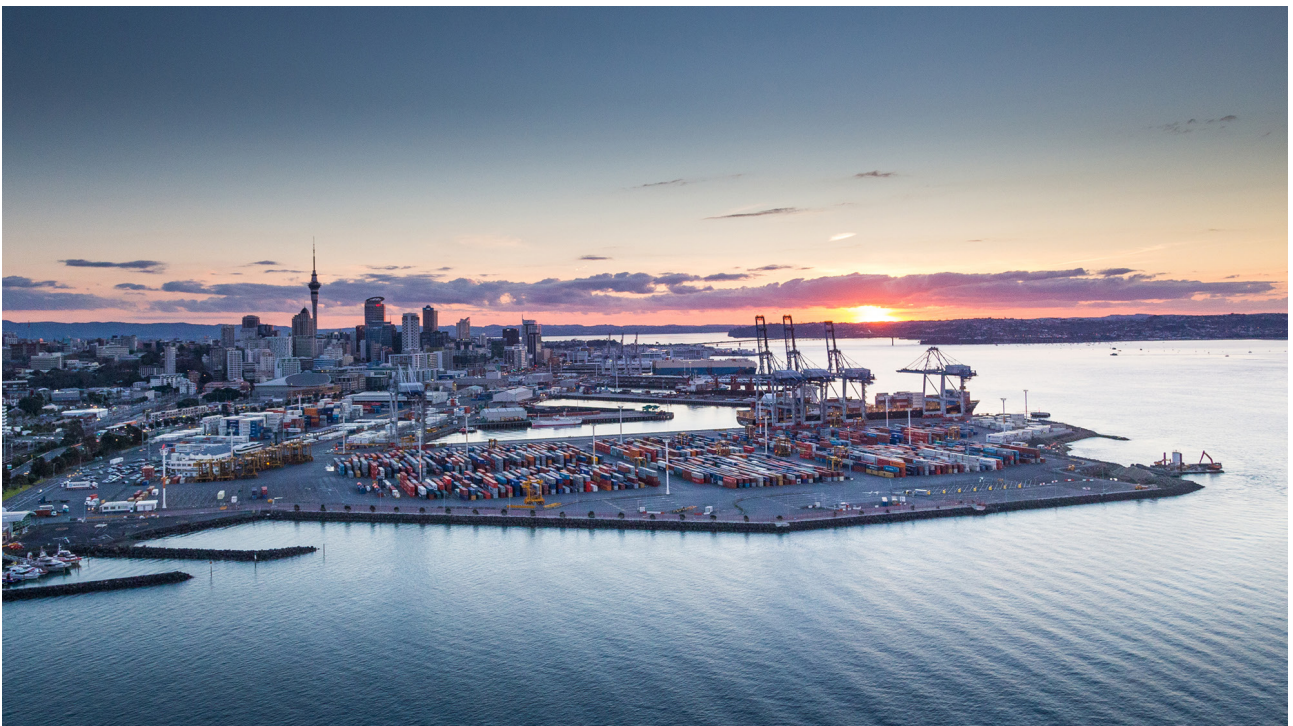
Working closely with our clients, Port of Auckland Limited, Auckland Transport and Kiwi Rail we are delivering an electrolyser based Hydrogen production and storage facility on the city waterfront which will provide decarbonised, compressed Hydrogen fuel to integrated port vehicles and city buses.

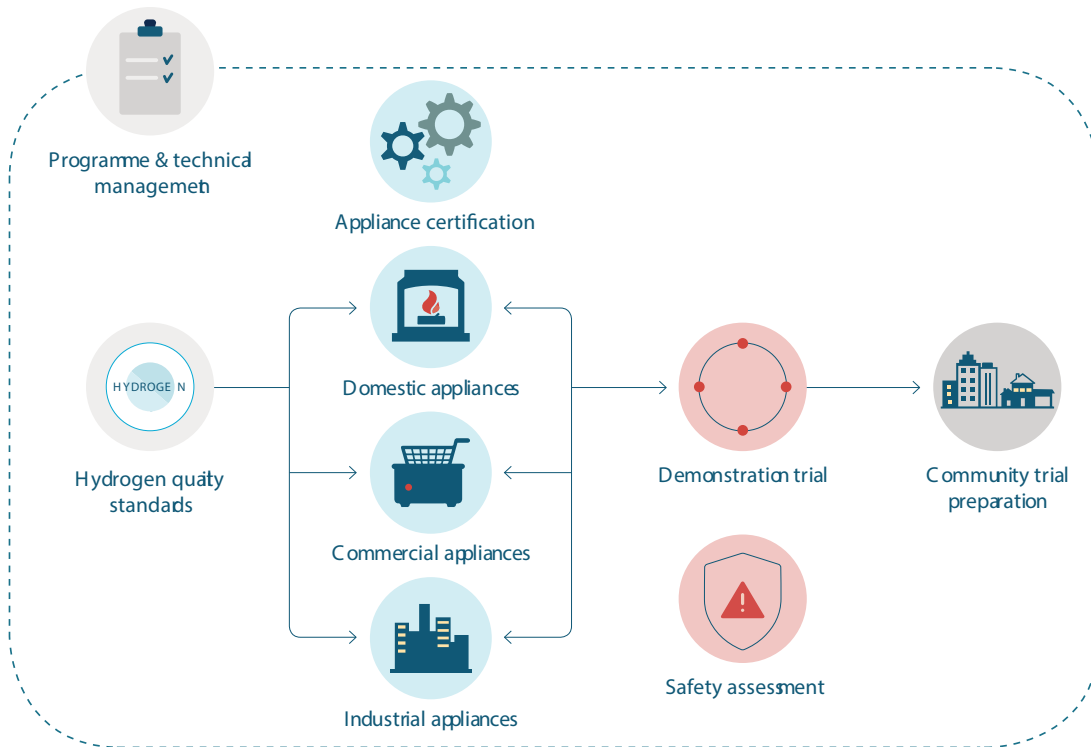
Our active involvement started at concept stage and has progressed through preliminary and detailed design, on to specification and procurement from the global supply chain and in to delivery.

As one of the first projects of its kind in the southern hemisphere the New Zealand regulatory and legislative setting for Hydrogen was nascent.

Our Hydrogen team drew together precedent and experience from around the world to inform and shape effective risk and safety management.

This industry leading project will significantly contribute to Auckland's target of becoming a zero emissions port by 2040.





Hy4Heat Hydrogen heat decarbonisation options

Major evidence led, multidisciplinary evaluation of Hydrogen derived heating, informing UK Government decision making on future decarbonisation policy.

Arup is driving this £25M government innovation programme designed to evaluate, de-risk and demonstrate the use of Hydrogen for heating homes and businesses.

This three year feasibility study includes: a definition of Hydrogen quality standards, development of domestic appliances for use with Hydrogen gas, safety and risk assessment and preparation for community trials.

Drawing together and commissioning world leading skills from the Hydrogen community Arup is central to the delivery of this complex, innovative and technically advanced multi-stakeholder programme.

Engagement with the technical and public stakeholders is a key facet of this programme. With this in mind we developed a website communicating various facets and findings.



Hydrogen powered trains: Route to enter into service

Evaluating the safety and risk related aspects of Hydrogen train deployment for RSSB.

The potential for Hydrogen to provide decarbonised traction energy, particularly on non-electrified rail routes is gaining increasing interest among train and rail network operators.

In anticipation of Hydrogen use in rail, the RSSB (Rail Safety and Standards Board) commissioned Arup to assess the likely implications of such development.

Arup undertook a broad ranging assessment of the various risks, safety implications and emerging precedent associated with Hydrogen use in rail.

Our work includes the development of a “Route map to enter service” for Hydrogen powered trains on the Great Britain mainline, including the high level operational concept along with associated operational hazards and regulatory obligations.

Establishing a regional Hydrogen economy in Northern England

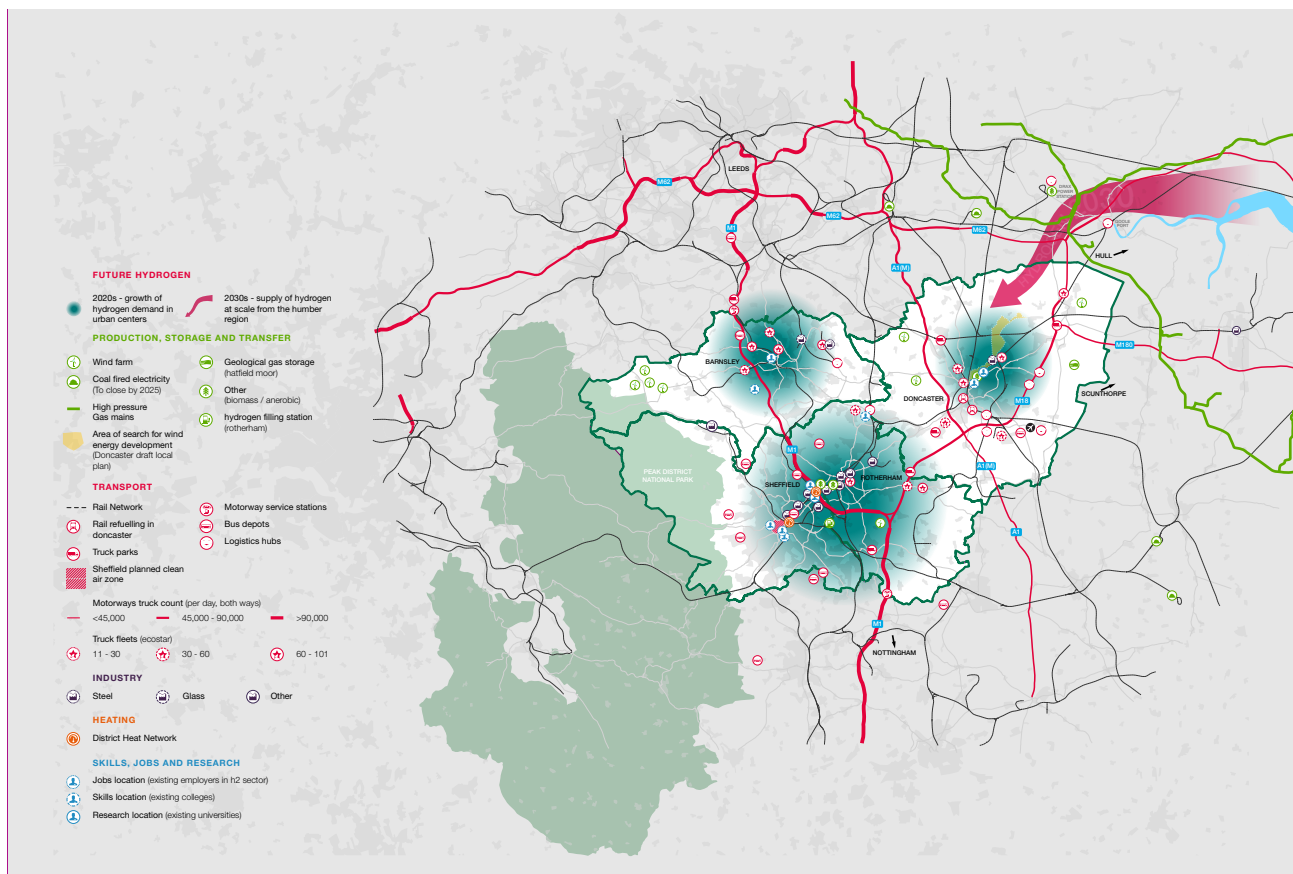
Development of regional opportunity in Hydrogen based heating, transport, and industrial sectors in northern UK.

In partnership with South Yorkshire regional authorities and key stakeholders we have drawn together a compelling vision describing the way in which Hydrogen can decarbonise this part of the North of England, while leveraging legacy assets and ascendant local skills.

Through Arup analysis followed by curated workshop engagement with utility, transport, housing and business stakeholders we identified opportunity across five themes: Production, storage and transfer, transport, industry, heating, jobs, skills and research.

Through detailed engagement and facilitation by our Hydrogen and regional experts we drew out and synthesized the knowledge and unique perspectives of a wide range of relevant organisations.

Joining public and private enterprise, the Arup team delivered the first step towards establishing a deliverable pipeline of Hydrogen focused projects in the region.



Project Methilltoune Hydrogen supply programme

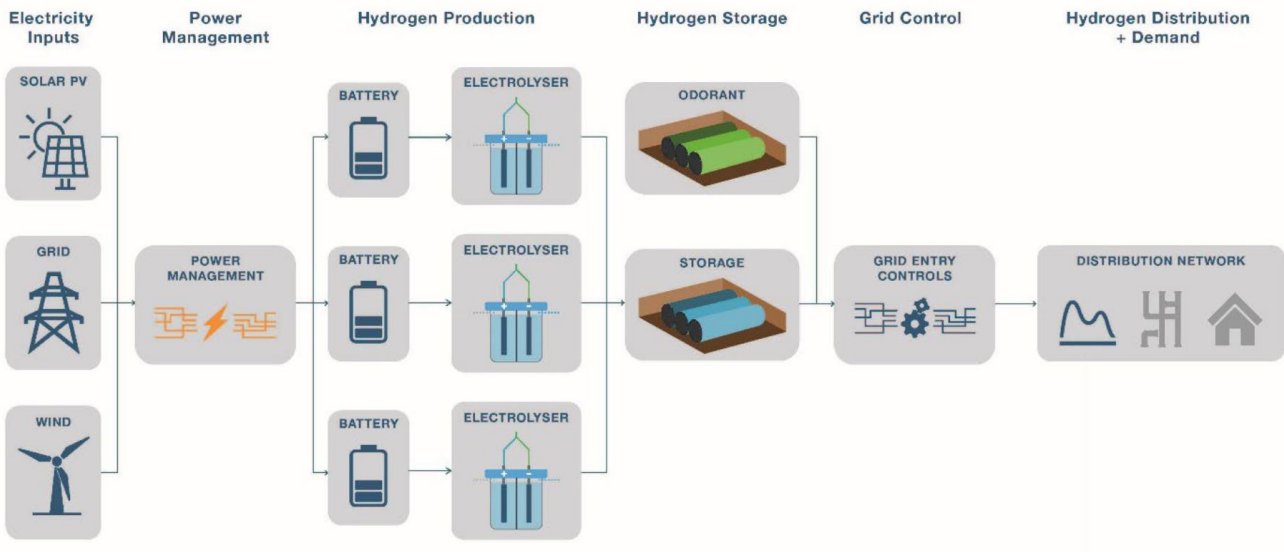
Increasing the bulk supply of renewable energy derived electrolytic Hydrogen in the existing natural gas network.

Engaging a system wide approach we are drawing together the features and characteristics necessary to deliver consistent and reliable Hydrogen for cooking, heating and hot water in a large scale residential context.

The system approach means that we are able to consider the various interactions, interdependencies and modulation which can be applied to low carbon electricity inputs through power management, variable

Hydrogen power to gas production, molecular or electron energy storage integrated to suit gas and electricity network constraints and requirements.

Our feasibility study and future demonstration project is designed to provide the technical, economic and safety case necessary to deliver a 100% Hydrogen fueled heating network which is both scalable and replicable.





New Zealand Government Hydrogen green paper

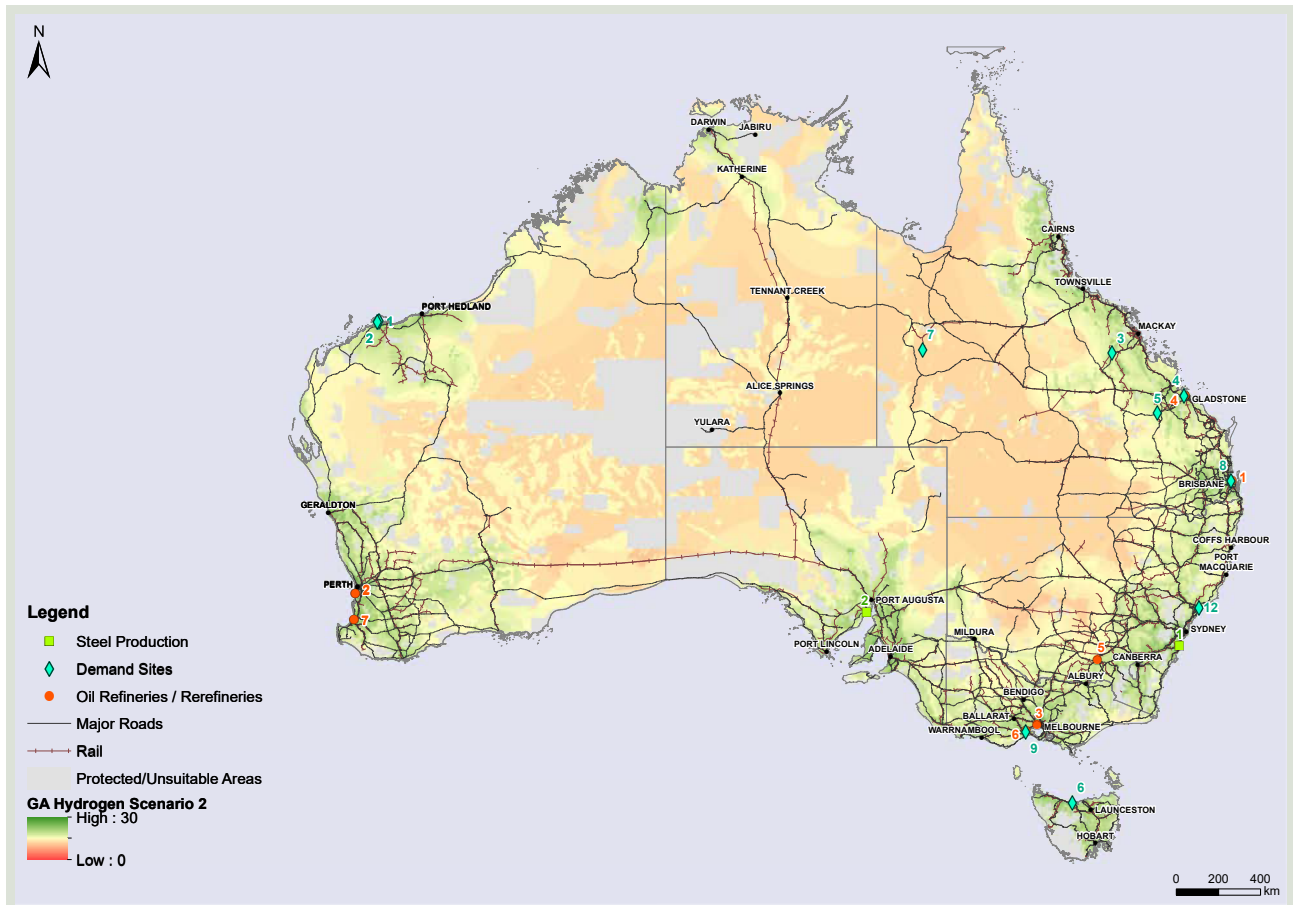
We engaged, evaluated, developed and communicated the New Zealand government perspective and public engagement on Hydrogen.

In close cooperation with MBIE (Ministry of Business, Innovation and Employment) officials, our international Arup team articulated the opportunity afforded by New Zealand’s prolific natural resources and environmentally conscious national psyche to be among the leading Hydrogen adopting nations.

The Arup authored Green Paper was presented by Hon Dr Megan Woods, Minister of Energy and Resources as a key enabling component of the country’s legally binding net-zero 2050 emissions target.

The paper addresses a broad range of topics, including: Potential growth for energy, transport, industry and export. The potential for Hydrogen to provide a just transition to zero net carbon. International partnership potential and alignment with indigenous cultural beliefs.

By combining our international Hydrogen experience with in-country understanding of government, infrastructure, energy and transport considerations we were able to deliver a very well received and informative impetus to the Hydrogen agenda in New Zealand.



Australian Hydrogen hub study

Opportunity and viability evaluation of Hydrogen hubs exporting green Hydrogen around the world.

On behalf of the Energy Council Hydrogen Working Group of the Council of Australian Governments (COAG) we produced a key technical study describing the opportunities and solutions which could derive from Australian Hydrogen export hubs.

This was a key accompanying document to Australia’s National Hydrogen Strategy recently announced by the Minister of Energy & Emissions alongside the Minister for Resources and Northern Australia.

We evaluated the existing supply chain infrastructure which could be re-purposed for Hydrogen while also assessing the resources and skills available to develop additional infrastructure.

A synoptic analysis of potential hub locations was undertaken, based on an Arup derived assessment criteria development and hub assessment framework.

Our work was undertaken through interviews and in close conjunction with a wide range of stakeholder organisations across business, government, industry bodies and the Hydrogen supply chain.

Project Cavendish Hydrogen hub

Detailed evaluation of blue Hydrogen production and green Hydrogen import infrastructure on the Isle of Grain feeding into London, UK.

On behalf of National Grid, Cadent, SGN and in conjunction with Shell and Uniper we are undertaking a detailed feasibility study. We are examining a potential Hydrogen hub on the Isle of Grain in Kent, where production, importation, storage and subsequent distribution to London and southeast England could be established.

Our focus includes identification of challenges and associated solutions across technical, economic, environmental and societal aspects, targeting first assets in place by 2025.

Combining our wide ranging technical and programme management teams to deliver this complex multi-disciplinary feasibility study we have covered a wide range of topics from network capacity (natural gas, electricity and carbon dioxide), land availability and ownership, co-located facilities and cross-sector opportunity, particularly in the decarbonisation of public transport and domestic heat.



SYPTE Hydrogen bus concept

Our study explored, evaluated and developed the concept of low-emission Hydrogen fueled buses in Sheffield, UK.

Drawing upon Arup Hydrogen bus experience in Canberra, Auckland, Dubai and London, this leading edge feasibility study concluded that there is an exciting, viable opportunity for zero emission Hydrogen buses to compete economically with conventional vehicles.

Our advice provided valuable contemporary insight to the South Yorkshire Passenger Transport Executive (SYPTE) through impartial, objective comparative analysis of Hydrogen, electric and conventional means of bus decarbonisation.

A key component of our work was the modeling of duty cycles associated with particular bus routes, taking into account the topography, distance and depot proximity, enabling us to determine the most effective vehicle type for specific applications.





Global Hydrogen refueling stations background review

Detailed evaluation of the global HRS landscape to inform the City of Perth, Australia on the maturity and market status of Hydrogen refueling.

Arup brought together a range of contemporary Hydrogen Refueling station market maturity assessment information from around the world to inform the City of Perth, Western Australia on production, transshipment, storage and dispensing.

Constraints and opportunities were mapped from a Perth perspective, including air quality, carbon emission reduction, noise reduction, city reputation, first mover advantage, electricity grid provision, safety and consumer acceptance.

We recommended a series of steps for the City to take, including a stakeholder engagement plan, Hydrogen refueling station location optimisation analysis as well as establishment of opportunities associated with existing municipal vehicle fleets and carpark infrastructure.

We also addressed information relating to Hydrogen production cost reduction trajectory and prospective price point.

ARUP

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