

ENERGY HUB PROJECT PHASE 2

Energy Hubs Phase 2 Public Report Part 2: Clean Fuels Transition Strategy

A network of Energy Hubs could convert Scotland’s constrained renewable resources into affordable, home-grown clean fuels, creating a practical route to market for stranded wind, reducing reliance on imported fuels, supporting industrial renewal and high-quality jobs, and providing the foundation for a resilient UK clean fuels sector.

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The United Kingdom has reached a critical moment in its energy transition. Without rapid action on fuels as well as electricity, the country risks an energy-system rupture rather than a managed transition.

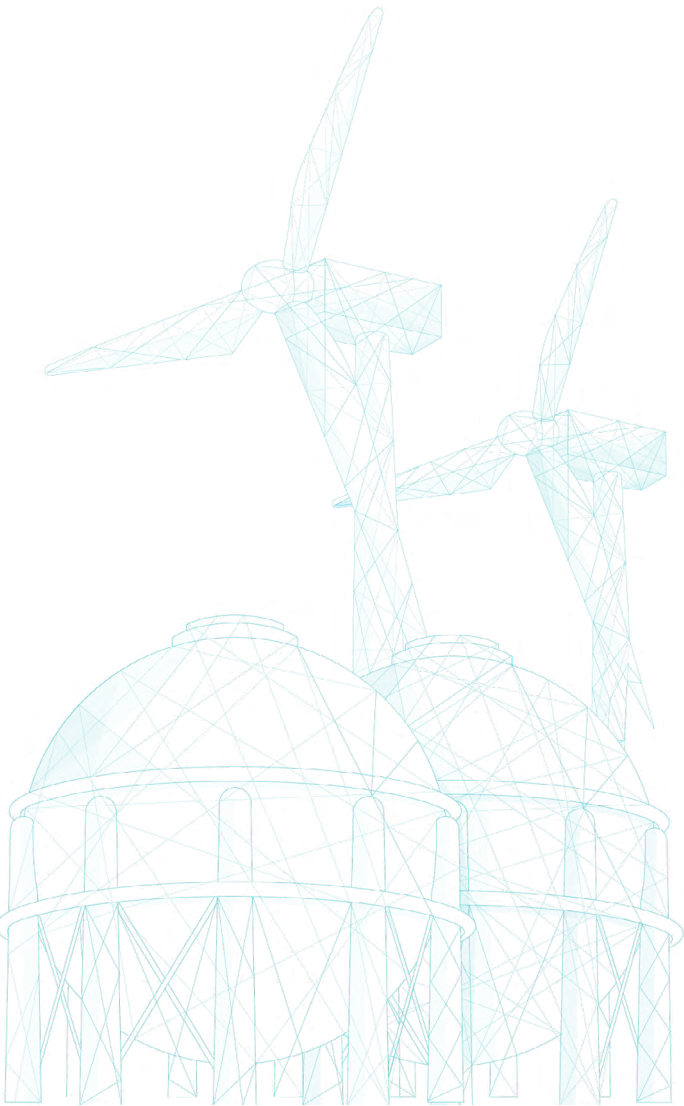
Recent price shocks and geopolitical instability have exposed how vulnerable the UK remains to imported fuels and volatile global markets. The pressures at the heart of the energy trilemma are intensifying, as pressure from the cost-of-living crisis, growing energy security concerns and legally binding net zero obligations converge.

Without a credible domestic clean fuels strategy, the UK risks missing hydrogen and wider decarbonisation targets, increasing dependence on imports and facing a disorderly transition marked by higher costs, lost jobs, and stranded assets. This report sets out a different path: A Clean Fuels 2035 Mission designed to build a home-grown, clean fuels industry that strengthens energy security and provides a long term replacement for declining oil and gas employment.

Drop-in clean fuels offer the fastest and least disruptive route to decarbonising the sectors that are hardest to electrify. The analysis in this report also shows that clean fuels can provide an alternative route to market for Scotland’s renewable power resources: by bringing demand to generation. A network of Energy Hubs can unlock stranded wind behind the B6 boundary, avoid multi billion pound HVDC reinforcement, and deliver up to 10 GW of wind-coupled electrolysis by 2035 as the first step towards 40 GW by 2050. In doing so, this pathway could support tens of thousands of high-quality jobs, reverse depopulation in rural and coastal regions, and reduce emissions by 27 MtCO₂ a year.

Realising this opportunity will require streamlined regulation, lower-cost long-term power arrangements for electrolysis, and strong central leadership able to align planning, networks, markets and end-use demand.

Over the longer term, ambitions for multi-gigawatt hydrogen production and clean fuels will only be credible if near-term low-carbon hydrogen production is established first. The immediate priority is therefore to develop demand-led Energy Hubs at commercially meaningful scale before 2035. A coordinated Clean Fuels 2035 Mission is needed now to drive that first wave of projects and to lay the foundations for subsequent five-year Clean Fuel Missions through to 2050.



The Energy Hubs Project

The Energy Hubs Project is one of seven projects within the Net Zero Technology Transition Programme (NZTTP).

The Energy Hubs Project, led by Net Zero Technology Centre (NZTC) and partners, has delivered over 25 detailed studies examining how Scotland can convert its natural energy resources into clean fuels and hydrogen at scale.

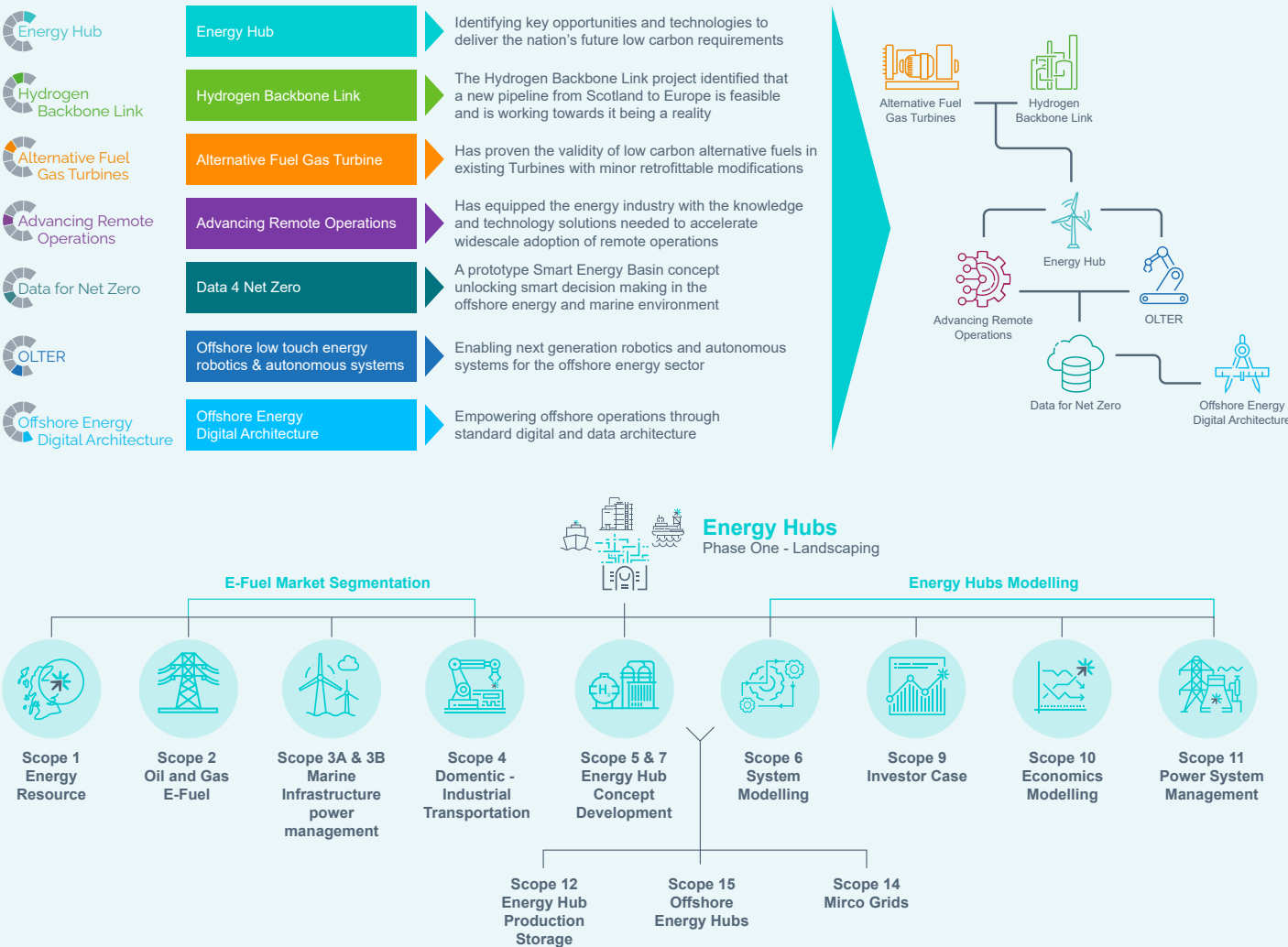


Figure 1 Energy Hubs Phase 1 Scopes of Work

Phase 1 of the Energy Hubs Project addressed key considerations around the creation of Energy Hubs across Scotland and concluded in 2023. The Phase 1 public report, available to download on the NZTC website, provides an overview of the main findings from this work.

“Energy Hubs” are a site or area that combines various technologies driving efficiencies of scale and the sharing of site facilities. An Energy Hub is a geographic location (region, city, island, industrial cluster) that can potentially host the entire hydrogen value chain, from production, storage, and distribution to end-use.

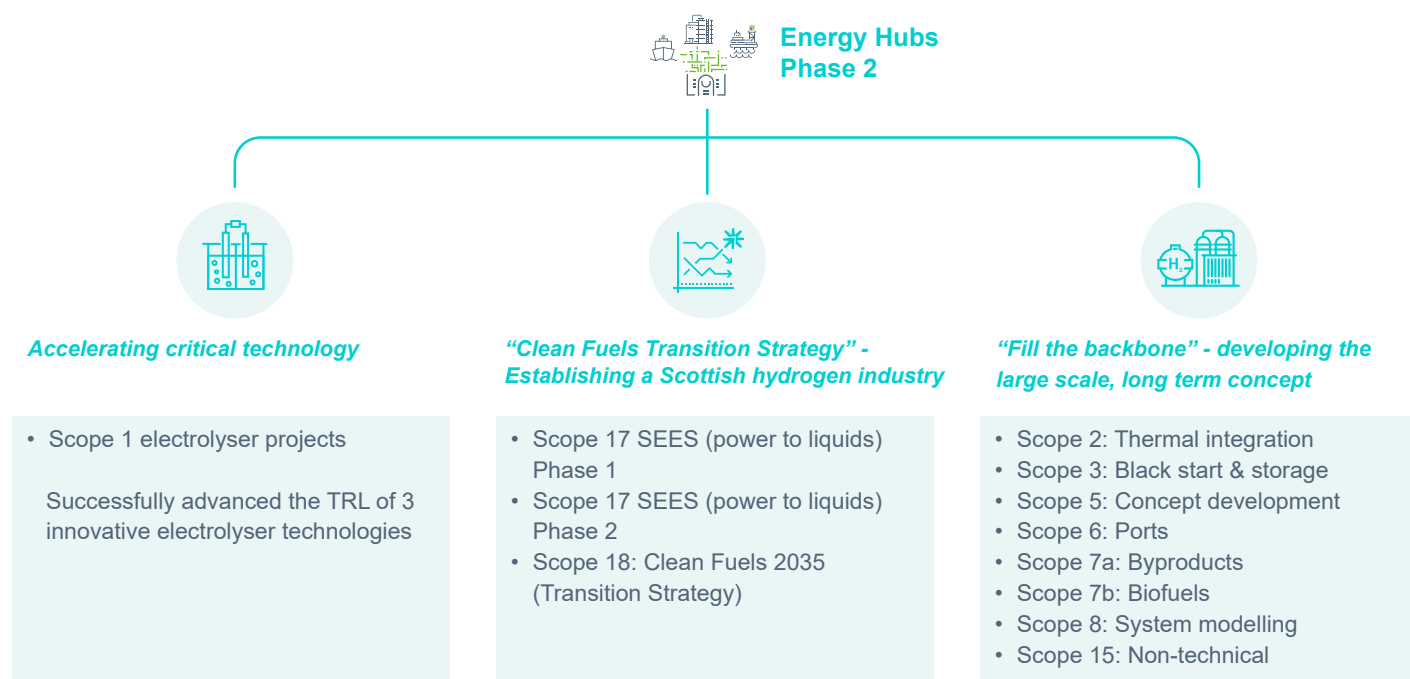


Figure 2 Energy Hubs Phase 2 Scopes of Work

Phase 2 of the Energy Hubs project built on the findings and recommendations of Phase 1 and focused on three main areas of work, with the outputs from that work summarised across three public reports.

Those reports are:

- Energy Hubs Phase 2 Public Report Part 1: Accelerating Critical Technology
- Energy Hubs Phase 2 Public Report Part 2: Clean Fuels Transition Strategy (This document).
- Energy Hubs Phase 2 Public Report Part 3: Fill the Backbone

For further details or for more information on the 25+ studies delivered through the Energy Hubs Project, please contact NZTC.

This Report

This document summarises the work carried out during Energy Hubs Phase 2 (NZTC, 2026) to develop a strategy for the near-term clean fuels transition. Its main focus is hydrogen as a feedstock for clean fuels, especially liquid drop-in fuels that can work with existing engines, turbines, fuel storage systems and fuel transport infrastructure.

This report draws on the work delivered during Scope 18, including spatial analysis, stakeholder engagement, case studies and policy assessment, to examine how clean fuels production could scale in Scotland and support wider UK energy goals. It also examines the barriers currently preventing these projects from progressing at pace, including power costs, planning complexity, market uncertainty and the absence of a clear mission led framework.

A central element of Energy Hubs Phase 2 was the construction of detailed mathematical models to optimise the economics of an e-fuels plant, delivered through Scope 17 Phases 1 and 2. The findings are crucial to demonstrating the economic feasibility of clean fuels production in Scotland and are also summarised in this report.

A Clean Fuels Strategy Is Needed

Electricity is only part of the story.

The UK has made real progress on cleaning up electricity, and the UK Government Clean Power 2030 Mission now aims for at least 95% clean power by 2030 (UK Government, 2024). Yet around three-quarters of the UK’s primary energy still comes from fossil fuels (DESNZ, 2026), much of it as liquid fuels for aviation, shipping, road and rail.

Energy security is national security:

Recent geopolitical shocks, including the wars in Ukraine and Iran, have highlighted how exposed the UK remains to global fuel price spikes and supply disruptions. If the country is to deliver both security of supply and security of cost, the clean power programme must be matched by an equally ambitious clean fuels programme that builds domestic manufacturing capability rather than relying on imports.

NESO’s modelling shows that even in a net zero world, the UK cannot rely on electricity alone.

The NESO Holistic Transition pathway predicts that, even with a fourfold increase of Primary Electricity over just 24 years, clean molecules will supply around 28% of primary energy by 2050 (NESO, 2026). This includes 196 TWh of biofuels and 120 TWh of low-carbon hydrogen. Around 89 TWh of that hydrogen demand is expected to be met through electrolysis, requiring roughly 40 GW of new wind-coupled to 40GW of electrolyser capacity - around twenty times the total global installed electrolyser capacity at the end of 2024.

shipping, aviation, power generation and industry, each taking roughly a quarter. These sectors depend heavily on fuels that are safe, energy-dense and compatible with existing equipment.

Drop-in fuels are the fastest, least disruptive, and most scalable pathway to decarbonising the UK’s most challenging sectors.

Drop-in fuels can be blended into, or substituted within, existing systems with minimal changes. Examples include sustainable aviation fuels as a replacement for kerosene, or e-diesel and e-methanol that can be handled through established storage and transport infrastructure. Their value lies in accelerating deployment and decarbonisation without waiting for the wholesale replacement of engines, pipelines and bunkering assets.

Just Transition and National renewal:

Over the past decade, the UK’s upstream and downstream fuels industries have already lost thousands of jobs, with the oil and gas workforce (around half of which is based in Scotland) shrinking by roughly 70,000 to about 115,000 people (Cook, 2026). Without a long-term replacement for declining oil and gas activity, many communities in Scotland face a deeply uncertain future.

The hydrogen demand is spread across four sectors -

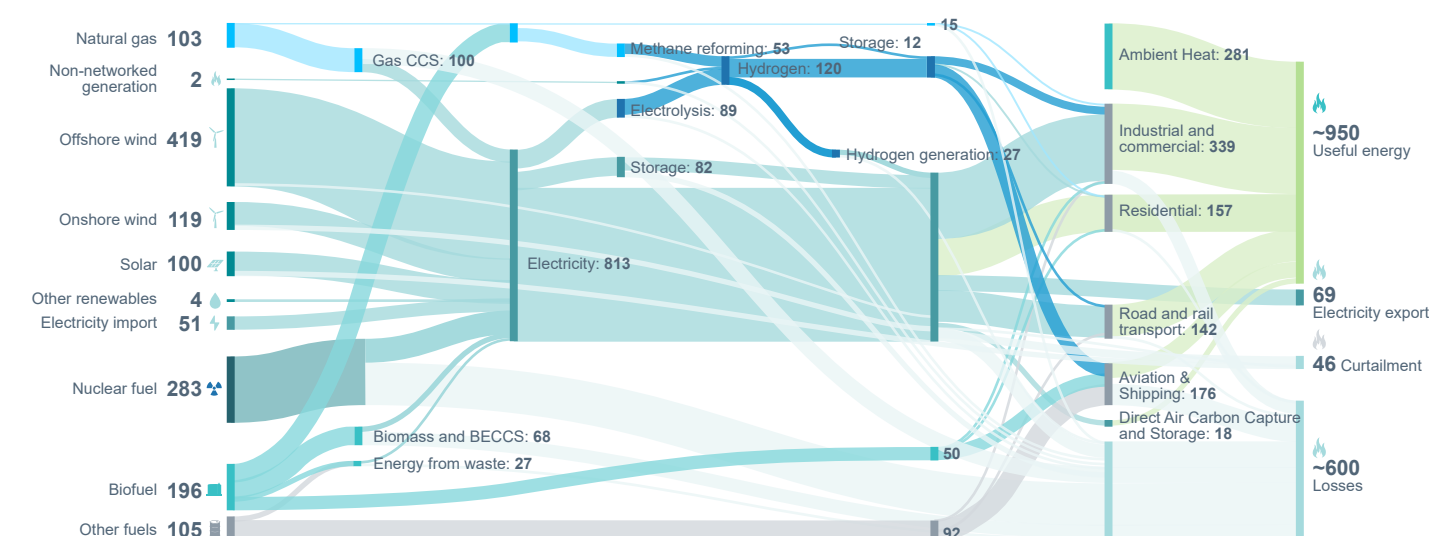


Figure 3: NESO 2025 FES Holistic Transition Sankey

Scotland's Opportunity:
From Constrained Wind to Clean Fuel Hubs

Scotland has the natural capital to become a clean energy powerhouse for the UK and beyond. It combines world-class wind resources, including record-breaking onshore capacity factors, with extensive land and sea areas suitable for infrastructure, abundant freshwater and seawater, deep-water ports, an experienced oil and gas supply chain and a workforce whose capabilities are already highly transferable to clean power and clean fuels production.

Much of this potential is currently stranded behind grid bottlenecks. Transmission constraints at the Anglo-Scottish “B6” transmission boundary are driving record levels of reinforcement and curtailment: wind farms being paid to switch off because the grid cannot handle their output. In 2025, the UK spent nearly £1.5 billion on curtailment (Rob Hawkes, 2026) - and about 98% of that curtailment occurred in Scotland (Montel, 2026).

Even with planned reinforcements, around 40 GW of Scotland’s planned wind capacity will remain grid-stranded or grid-constrained unless new demand is created close to where power is generated. Without that local demand, curtailment costs could approach £8 billion per year by 2030 (NESO, 2025).

The traditional solution has been to build more high-

voltage direct current (HVDC) links from Scotland to England. These projects are extremely expensive: for example, the 2 GW Eastern Green Link 2 from Peterhead to Hull is expected to cost around £4.3 billion. Fully unlocking Scotland’s resources through this route alone would require many more such links, further increasing system costs and network charges. An alternative is to bring demand to the generation.

Producing clean fuels in Scotland could offer a stronger affordability and value-for-money case for HM Treasury. “Wind-to-molecule” solutions provide an alternative route to market for stranded electrons by using wind power to produce hydrogen and synthetic fuels, converting variable renewable electricity into storable and transportable clean fuels for sectors that are difficult to electrify.

A balanced investment portfolio that supports the additional build out of HVDC links to move electrons while also supporting the required full-chain wind-to-molecule systems. This focused place and demand-based approach located alternative solutions where power constraints are greatest and draws on the existing capabilities of the oil and gas supply chain to develop equivalent upstream, midstream and downstream capacity for clean fuels in both gaseous and liquid form.

A natural capital, place-based approach:

The answer proposed in this report is a network of distributed Energy Hubs located at existing and new industrial sites across Scotland that allow clean fuels to be produced directly at points of power constraint. This will unlock stranded wind resources in locations that already have the land, deep water ports, access to water, and established energy sector supply chain and skills.

This place-based approach will:

- deliver improved affordability and value for money for HM Treasury,
- provide a commercially viable route to market,
- reduce curtailment,
- avoid several multi-billion-pound HVDC reinforcement costs north of the B6 boundary,
- offer a lower-cost whole energy system alternative to transmitting electricity south, and
- as a result, strengthen system resilience, accelerate decarbonisation, and secure long term economic opportunities for Scotland’s workforce and industrial regions.

Even so, progress is likely to remain fragmented, slow and more expensive unless planning, networks, markets and demand are aligned through a mission-led framework.

A “Clean Fuels Mission” is needed, starting with a 2035 Mission. This should be integrated into Pillar 2 of the UK Government’s Clean Energy Superpower Mission and should be followed by subsequent five yearly missions through to 2050.

Value proposition of the
“Clean Fuels 2035” Mission

The Clean Fuels 2035 Mission will deliver:

- 1.The production and supply of clean fuels at the scale needed to meet the UK’s Net Zero needs whilst meeting Treasury’s affordability and Value for Money criteria.
- 2.Removal of Transmission Network constraint, by enabling the construction of planned and future on and offshore wind farms whilst meeting Treasury’s affordability and Value for Money criteria.

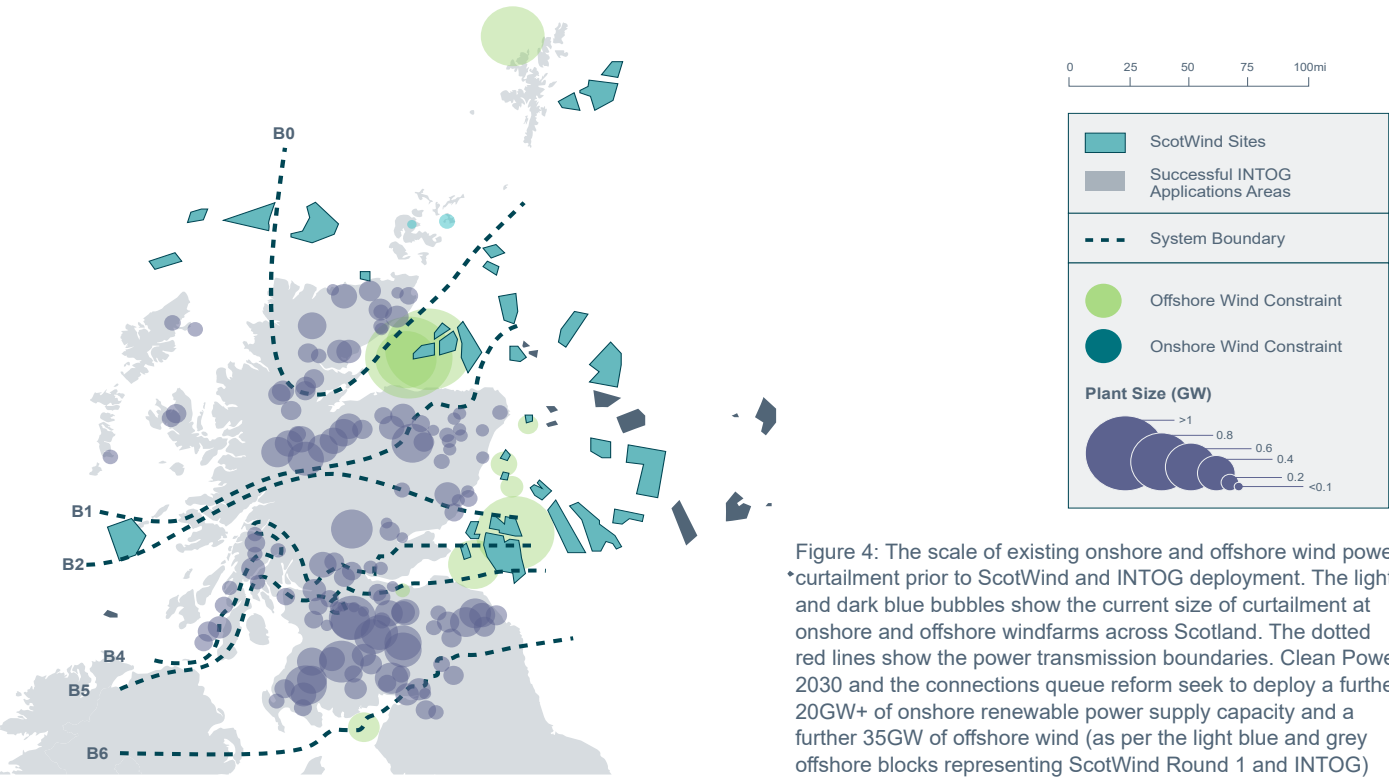
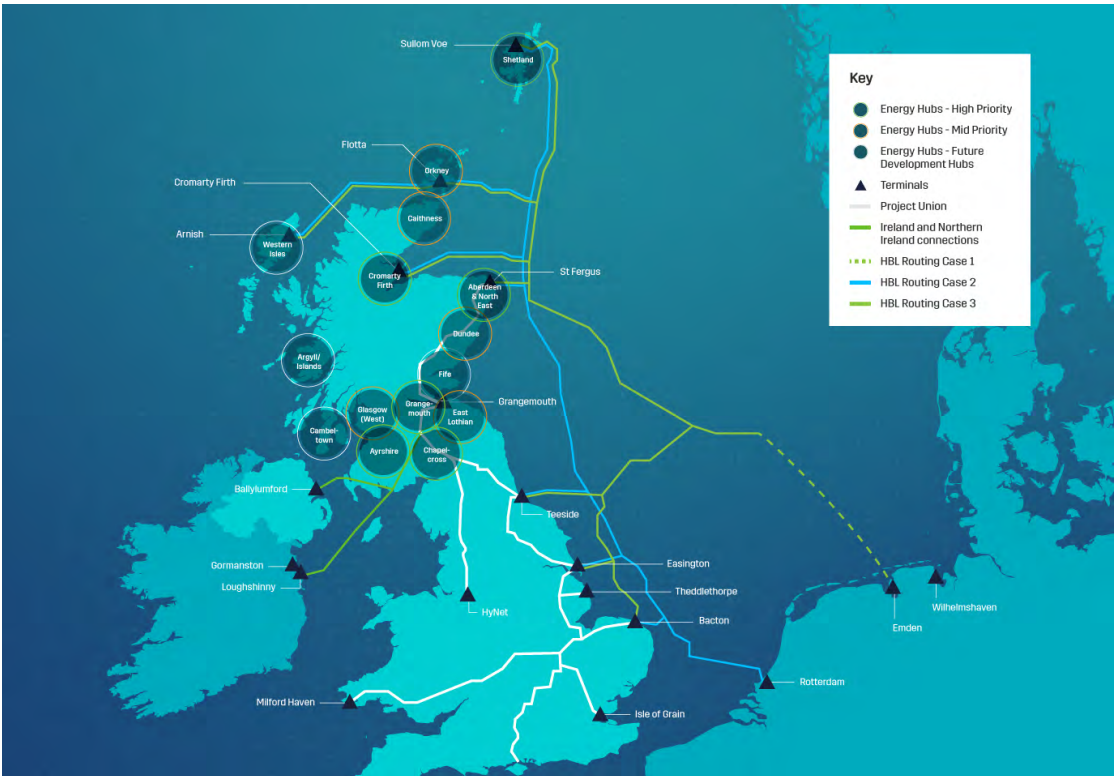


Figure 4: The scale of existing onshore and offshore wind power curtailment prior to ScotWind and INTOG deployment. The light and dark blue bubbles show the current size of curtailment at onshore and offshore windfarms across Scotland. The dotted red lines show the power transmission boundaries. Clean Power 2030 and the connections queue reform seek to deploy a further 20GW+ of onshore renewable power supply capacity and a further 35GW of offshore wind (as per the light blue and grey offshore blocks representing ScotWind Round 1 and INTOG)





Scottish Engineered Energy System Modelling

Producing clean fuels in Scotland at a commercially feasible price point.

As part Energy Hubs Project Phase 2, Veri Energy and Think Tank Maths (TTM) developed and optimised advanced mathematical models of a wind-powered e-fuels plant at Sullom Voe Terminal in Shetland (ThinkTankMaths, 2026). These models incorporated OEM data, detailed CAPEX/OPEX estimates, stochastic wind and meteorological modelling and optimised control strategies for electrolyzers, storage and grid interaction. Mathematical methods were used to holistically represent uncertainty, allowing the economics of an e-fuels plant to be tested.

This work was conducted in two stages. The first phase developed a model for a demonstrator plant producing green e-methanol from a dedicated wind farm. This, alongside a detailed economic study, showed that e-methanol could be produced at a levelised cost competitive with e-methanol imports.

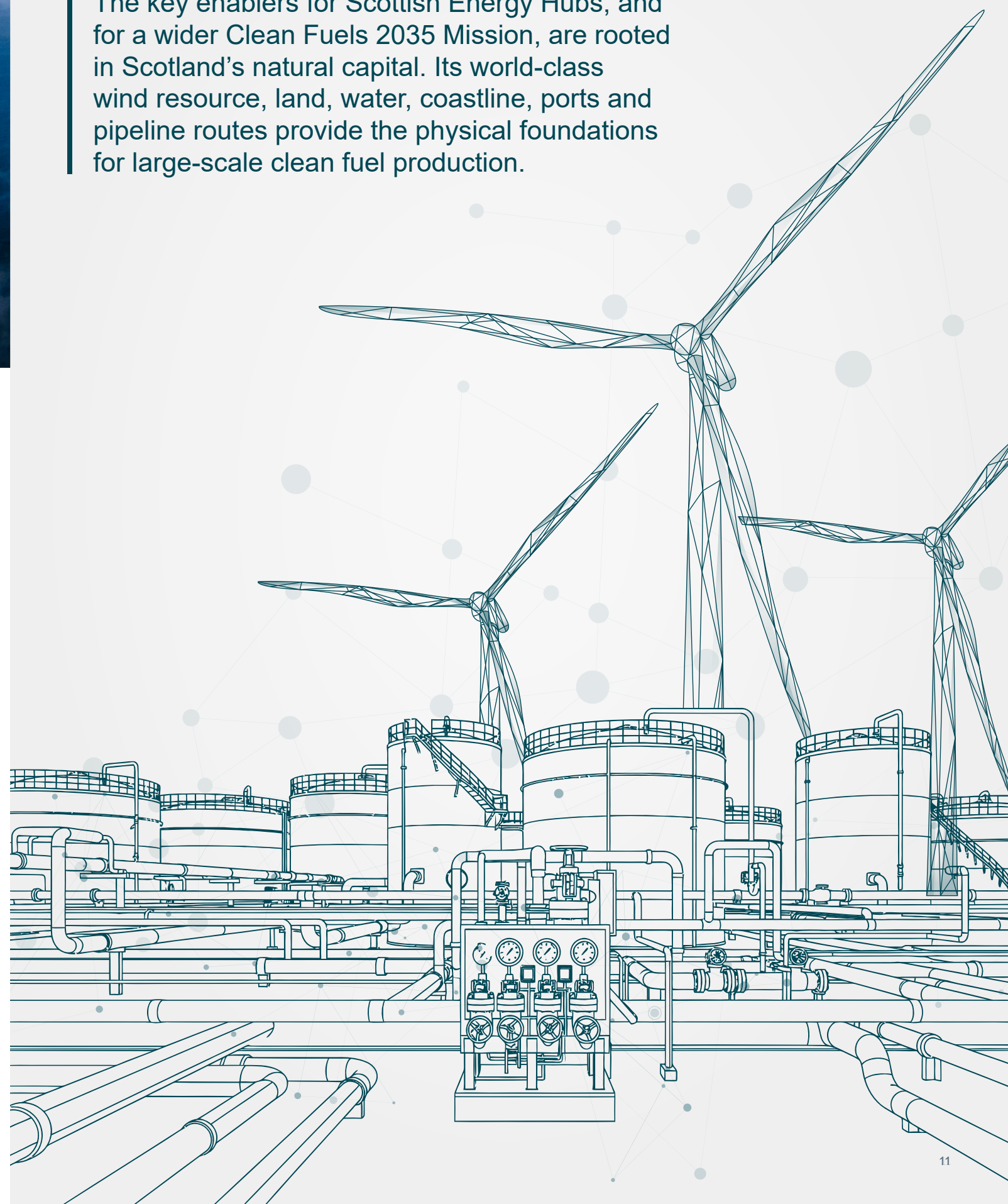
The second phase extended and updated the model to examine a larger-scale e-fuel plant producing Sustainable Aviation Fuel (SAF) as the end product.

This modelling was a major part of the Energy Hubs Project and shows producing e-fuels from renewable resources in Scotland can be economically feasible if projects are well located and supported by the right policy framework.

The next step is to expand and enhance this model so it can test alternative technologies, further optimise plant design and improve transferability to sites beyond Shetland.

This report recommends that this robust, site-based modelling approach is applied to other potential e-fuels plant sites.

The key enablers for Scottish Energy Hubs, and for a wider Clean Fuels 2035 Mission, are rooted in Scotland's natural capital. Its world-class wind resource, land, water, coastline, ports and pipeline routes provide the physical foundations for large-scale clean fuel production.



Clean Fuels Energy Hubs

Alternative routes to market for Scotland’s resources

Planned grid reinforcement between now and 2040, estimated at around 8 to 12 GW, should relieve some existing constraints but would still leave more than 40 GW of planned renewable capacity having no clear route to market. Without an alternative pathway, that

capacity could be cancelled or require additional billions in network infrastructure beyond what is already planned. Rather than accept this gap, why not enable “Wind-to-Molecule” solutions that meet the 40 GW plus clean fuel requirement?

Figure 5 shows two examples of how an alternative grid system “Relief Valve” could be enabled.

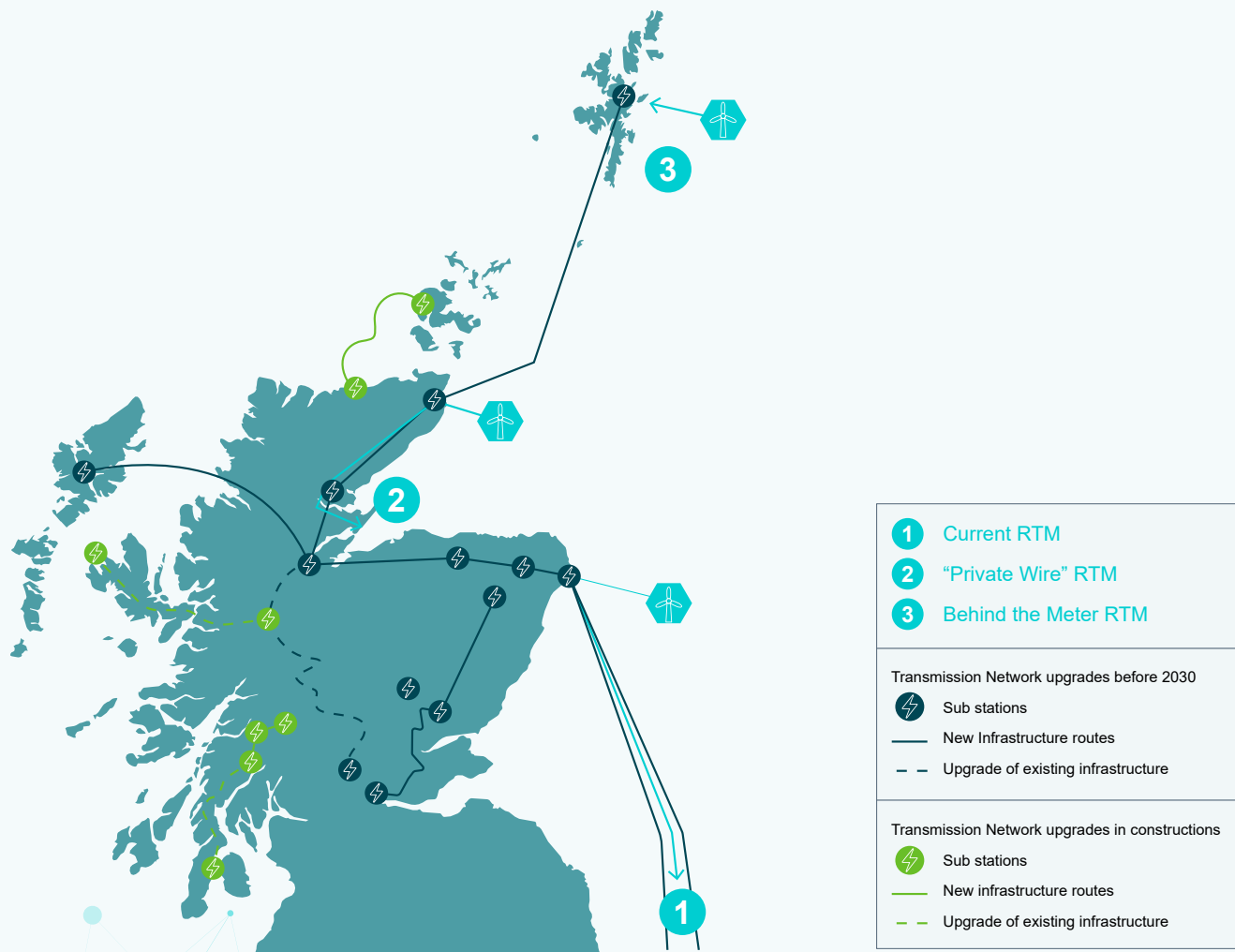


Figure 5 Alternative Routes to Market (RTM) for electrons and molecules

1



Current Route to Market Example:

Under the current route to market model, A 2 GW windfarm seeking to connect to the North of Scotland Transmission system will not see its electrons flow to market because the network is heavily constrained. To enable that wind farm, the system operator would need to build matching transmission capacity, such as the 2 GW HVDC Eastern Green Link 2 interconnector from Peterhead to Hull. This could add more than £33/MWh in TNUoS charges for customers in England. If those electrons were then used to produce clean molecules within the Humber region, this would not represent the best Affordability or Value for Money outcome for HM Treasury.

2



“Private Wire” Route to Market Example:

A full chain Wind-to-Molecule model would allow an onshore or offshore wind farm to connect to the Transmission Network, while drawing power off within the same boundary region and reducing pressure on the wider system. For example, a 2 GW offshore wind farm connected at Spittal could supply 2 GW of electrolysis into the Inverness and Cromarty Firth Green Freeport, with power drawn off before it reaches the constrained Beaulieu Substation. Virtual linking of wind generation and electrolysis through telemetry would provide a real-time, distance-compensated correlation between fluctuations in wind generation and electrolyser operation. This approach could minimise additional transmission constraints and avoid the need for a further 2 GW HVDC link from northern Scotland to England. Under existing Electricity Act arrangements, this route may be enabled through an alternative CfD structure and a Corporate PPA, giving clean fuel producers access to lower-cost power.

3



“Behind-the-meter” Route to Market Example:

A behind-the-meter model would create a direct physical link between the wind farm and the clean fuel production facility. For projects above 100MW, this would require a change to the Electricity Act to have a direct physical link that enables load following electrolysis underpinned by a Corporate PPA. In the example shown, a 2 GW offshore windfarm would connect directly to 2 GW of electrolysis, thus avoiding the need for, and cost of, an equivalent 2 GW HVDC link. HM Treasury then achieves better Affordability and Value for Money by providing a £33/MWh “Grid Relief Availability Payment” to the full chain Wind-to-Molecule solution. Enabling a competitive power price, unlocks domestic clean fuel production, thereby helping UK-made clean fuels compete with imports.

Hub Archetypes

The design of each Energy Hubs must start with what is available and needed in each area. Locations with deep-water ports and strong links to aviation and shipping are more likely to favour liquid drop-in fuels, while inland or pipeline-connected sites may be better suited to gaseous hydrogen and derivatives for industrial feedstock and power.

Energy Hubs can interlink to create a broader “Super-Hub” ecosystem. For example, e-methanol produced in a Shetland Liquids Hub and hydrogen products from Gaseous Hubs in Aberdeenshire, Ayrshire and Chapelcross could be transported by vessel and pipeline into Grangemouth. Within the Multi Vector Grangemouth Hub, ammonia could be finished into green fertiliser, methanol upgraded into e-kerosene, etc. The e-kerosene would drop into the existing kerosene fuel bunkering at Grangemouth and its pipeline distribution network that serves several Scottish airports. The Multi Vector Grangemouth Hub would encompass biofuels, ammonia and methanol conversion as outlined in Project Willow.

Five broad Energy Hub archetypes were identified during the study:



Gaseous Hub



A Hub that converts wind power into gaseous hydrogen that is moved by pipe to points of conversion / end use.

Multi Vector Hub



A Hub that converts wind power into both gas and/or liquids and which may also vertically integrate by converting one or both into use products. All are moved by pipe and/or vessels to points of conversion / end use.

Liquids Hub



A Hub that converts wind power into ammonia, methanol, liquid hydrogen etc. That is moved by pipe or vessel to points of conversion / end use.

Finishing Hub



A Hub that receives clean gas or liquids from one or more Hubs and converts these into end use products, i.e. ammonia into fertiliser, methanol into e-kerosene etc.

Value Add Hub



A broader “Industrial Estate” that leverages any of the previous Archetype Hub’s infrastructure for existing / new adjacent industry through the direct electrification and/or use of electrolysis products and coproducts (electrolyser heat, oxygen etc), e.g. data centre, distillation, smelting, vertical farming etc.

Integration of the development of the UK’s required biofuel development should also be pursued where viable.

Spatial Analysis

GIS analysis was performed across 15 Scottish regions, to identify the most appropriate solutions for each location, and to identify which regions should come first in the build-out. Other regional locations within and out with Scotland could host regional Energy Hubs of varying scale. The 15 areas arose out of previously delivered Energy Hub reports and were socialised and validated with a wide range of stakeholders across several months.

Each region was assessed against a broad range of spatial datasets, including wind resource and curtailment, land availability, port and pipeline access, proximity to industrial demand, water availability, grid infrastructure and potential sources of biogenic CO2.

This spatial work allowed hubs to be sorted into archetypes and priorities rather than treated as a single, generic model. Areas with strong offshore wind and deep-water ports but relatively limited local e-fuels demand such as Shetland, emerged as prime candidates for liquids-focused production hubs exporting e-methanol and other fuels by ship. Regions like Grangemouth, with existing pipelines, refinery and chemicals infrastructure, scored highly as “finishing” and multi-vector hubs, ideally placed to convert imported intermediates (for example, e-methanol) into drop-in products like e-kerosene for aviation and distribute them through existing networks.



Figure 6

This assessment focused on the “natural capital” available at each location:

-  **Local Demand** – what demand for clean fuels exists within that region to gauge the opportunity for local supply.
-  **Routes to Demand** – Existing and planned ports and pipelines to gauge the ability to move product from the region.
-  **Existing Projects** – Existing and planned clean energy developments, both power and fuel.
-  **Land Availability** – Land with <5-degree slope, both brownfield and greenfield.
-  **Biogenic CO2** – Local sources and/or locations where CO2 could be brought into the region.
-  **Water** – A map of local sources of freshwater, seawater, and large industrial wastewater plants.
-  **Power and Power Availability** – Transmission infrastructure and regional clean power availability in 2025, 2030 and 2035.

A high-level overview of the conclusions of this assessment is shown in Figure 6.

	Natural Capital								
Energy Hub	Local Demand	Routes to Demand	Existing Projects	Land	Biogenic CO2	Water	Power 2025	Power 2030	Power 2035
Shetland									
Orkney									
Western Isles									
West Coast Isles									
Caithness									
Cromarty Firth									
Aberdeen & North East									
Dundee									
Fife									
East Lothian									
Grangemouth									
Campbeltown									
Glasgow (West)									
Ayrshire									
Chapelcross (Dumfries)									

Figure 6 summary and commentary of the GIS Mapping Assessment output for the 15 Energy Hubs

Development Priorities: Results

Insights and data from GIS mapping were used to identify the Energy Hubs with the strongest development potential, considering both initial deployable capacity and longer-term buildout potential.

As shown in Figure 7, six Energy Hubs were identified as “High development priority”. Together, these six hubs could deliver around 40 GW of clean fuel capacity, with a mix of gaseous hydrogen production, liquid fuel production, and finishing and blending facilities. A further five hubs were identified as “Medium development priority”.

	Hub Archetype				Development Priority (HML)
Energy Hub	Gaseous	Liquid	Finishing	Multi Vector	
Shetland					High
Cromarty Firth					High
Aberdeen & North East					High
Grangemouth					High
Ayrshire					High
Chapelcross (Dumfries)					High
Orkney					Medium
Caithness					Medium
Dundee					Medium
East Lothian					Medium
Glasgow (West)					Medium

Figure 7 High and Medium development priority Hubs

It is recommended that the six high-priority Energy Hubs form the initial focus of the Clean Fuels 2035 Mission. Collectively, these hubs will advance clean fuel production from bioenergy, CCS enabled hydrogen and electrolytic hydrogen, while enhancing existing strategic UK projects, such as ScotWind, Project Willow, Acorn CCS and the Scottish Cluster, Project Union Phases 2 and 3, and the Hydrogen Backbone Link. Medium Priority Energy Hubs can then follow on.

The Enabling Phases of capacity deployment across the High and Medium Priority Energy Hubs, supported by further GIS-based “natural capital assessment” could also help inform where future leasing opportunities are made available. This could include a potential ScotWind Round 2 designed around a full-chain “Wind-to-Molecule” outcome.

Realising the potential of these regional hubs will depend on frameworks that support investment. This means embedding Energy Hubs into regional and national spatial planning and supporting them through a coordinated programme of infrastructure development, market creation and policy reform.



Figure 8 Map High and Medium priority Energy Hubs

A Scalable route from early projects to multi-gigawatt deployment

Immediate action is needed, followed by a series of Missions

Long term, multi-gigawatt ambitions cannot be met without first establishing low-carbon hydrogen production in the near term. Urgent action is needed to establish credible, enabling capacity before 2035.

The UK Government set targets to deploy 1 GW of low-carbon hydrogen production capacity by 2025 and 10 GW by 2030, split between 4 GW of CCS enabled hydrogen and 6 GW of electrolytic hydrogen. However, progress through HAR1, HAR2 and the Industrial Cluster Programme suggests that 1 GW is unlikely to be operational by the end of 2030, missing the 2025 target considerably, let alone the 2030 target.

For this reason, a “Clean Fuels 2030 Mission” is not proposed: Meeting the low-carbon hydrogen demand implied by NESO’s Holistic Transition pathway would require around 3.4 GW of wind-coupled electrolytic hydrogen by 2030, which is not seen as realistic within current deployment timescales.

Instead, the recommendation is for a series of five-year Clean Fuels Missions, beginning with a Clean Fuels 2035 Mission targeting 22.5 TWh per year through 10 GW of installed capacity by the end of 2035. Subsequent missions will each add a further 8-10GW of installed capacity, building a national network of GW-scale Hubs.

These Clean Fuel Missions must deliver:



Demand flexibility enabled through
a) electrolysis load following directly or indirectly coupled wind power generation and
b) storage of feedstocks and final products;



Infrastructure and energy supply delivered through a whole-system, value-for-money approach to new onshore and offshore wind power, Energy Hubs and route to market infrastructure.



End Use switching enabling the transition from unabated fossil fuels to low-carbon clean fuels, with a particular focus on liquid “drop-in” fuels where these offer the fastest and least disruptive route to decarbonisation.

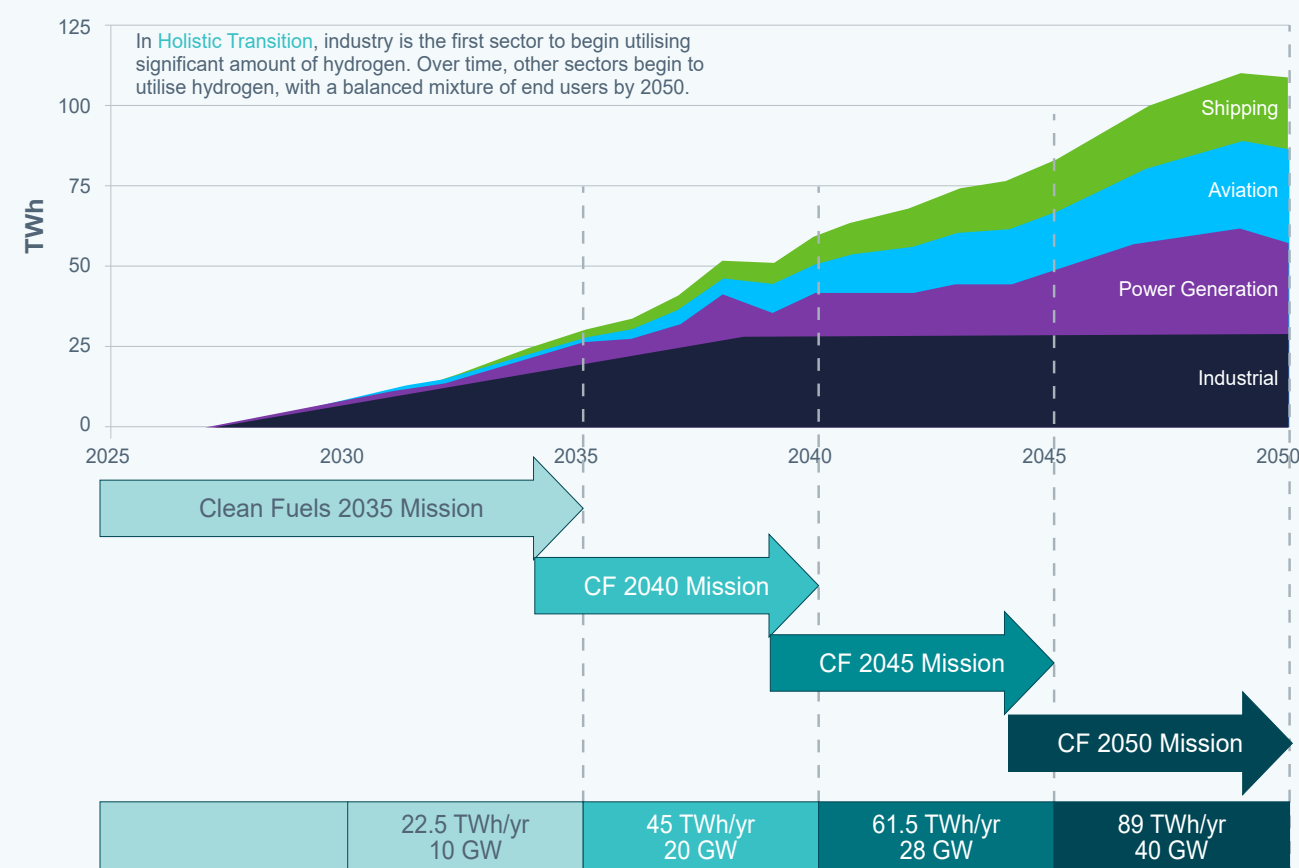


Figure 9 Deployment of Clean Fuels Missions to deliver 40GW+ of electrolytic hydrogen fuels for the UK by 2050. Holistic transition based on (NESO, 2026)

Early, enabling Projects: pre-2035

The period to 2035 should be used to establish a small number of pathfinder hubs or enabler projects. These projects should prove commercial structures, consenting routes, supply chain capability and routes to market, while being designed from the outset to scale into much larger regional systems over time. Each Energy Hub should sit within a Regional Energy Spatial Plan.

The scale of this first phase will vary by location. As a minimum, each enabling project is expected to use a power connection of at least 60 MW. There may be exceptions, for example where a sub-60 MW behind-the-meter direct connection to an existing or planned onshore wind farm enables a faster start. Some hubs may also be much larger from the outset. These early, smaller-scale hubs are expected to expand into hundreds of megawatts or multi-gigawatt systems as infrastructure and markets mature.

First phase Energy Hubs should be demand-led with sufficient evidenced offtake, have access to water and CO₂, be investable through a pre-2032 Final Investment Decision (FID) and, where possible, be capable of later optimisation to enable buildout from hundreds of megawatts to gigawatt scale and beyond.

Most pre-2035 capacity deployment is likely to focus on liquid clean fuel production.

Subject to access to power and biogenic CO₂, fuels could be transported by vessels from Shetland, Cromarty Firth, and Aberdeen & Northeast, while Grangemouth prepares to receive clean liquids for conversion. Grangemouth is also likely to develop feedstock production capacity of its own, although this will be limited by regional power constraints on both availability and transmission capacity.

10 GW of electrolysis by 2035:

The proposed Clean Fuels 2035 Mission would aim to deploy a total of 10 GW of wind power coupled to 10 GW of electrolysis, to produce 22.5TWh of clean fuels per year across the Energy Hubs. This is estimated to require 12 million cubic metres of water, 4 square kilometres of land, 2.3 million tonnes per annum of biogenic CO₂ and £34 billion of investment. This would require 1-2 GW deployed across each of the six high-priority Energy Hubs, and potentially some enabling capacity at the five medium priority Energy Hubs. Delivering 10 GW of wind and Energy Hub projects is estimated to require approximately 13,500 full-time individuals to operate, maintain, and manage the full chain clean fuel production systems created.

Although this is a substantial delivery challenge; it presents a significant opportunity for the existing UK fossil fuel supply chain to transition.

Early, enabling projects: Timeline challenges and schedule risks

Even relatively simple clean fuels projects are currently taking six to seven years to develop and construct. Each project is likely to require at least 3 years of pre-FID development and 3 years of post-FID development.

The pre-FID Critical Path is likely to be driven by: securing a grid connection, obtaining planning approval, and securing funding. Securing a grid connection can take 4-5 years or more at Distribution and 7-10 years or more at Transmission. Planning approval can take over three years, with additional schedule risk where new wind generation is being co-developed alongside the clean fuels project. The biggest schedule risk is policy uncertainty, and this is outside a developer's control.

Post-FID, the projects construction Critical Path will switch to long-lead time items. This may be driven by the lead times for electrolyzers and/or compressors, but it is most likely to be driven by the supply of transformers for which there is a global shortage.

Taken together, this points to a likely seven-to-ten-year timeline from project initiation to commercial operation and first production.

Projects starting in 2026 would therefore need sustained momentum to be producing before 2035. This is why this report recommends that early enabling phases should focus on brownfield sites with sufficiently sized grid connection to underpin the baseload needs (i.e., the synthesis unit) and, where possible, infrastructure such as deep-water ports for moving liquids.

The Clean Fuels Mission should build on the GIS mapping output and examine place-based solutions in further detail. The aim would be to identify "fast start" opportunities and develop a SWOT assessment for each Energy Hub, supported by a decision analysis tool, already developed, to comparatively assess different options. This will help focus resources on the hubs and projects most likely to progress at pace.

Post 2035 Buildout to 2050

The post 2035 buildout will see a further three-fold increase in deployed wind-coupled electrolysis capacity by 2050. This would continue to focus on scaling up the capacity of the six high-priority Energy Hubs identified earlier. In parallel, further capacity from the six medium-priority hubs can be deployed, particularly if an export strategy is approved by UK Government.

Delivering the Clean Fuels mission by 2050 is estimated to require 40 GW of electrolysis, 48 million cubic metres of water, 8.9 million tonnes per annum of biogenic CO₂ and 16 square kilometres of land, roughly equivalent to 2,500 football pitches. If concentrated across just five key Energy Hub locations, each site would need around 3 square kilometres of land (roughly 500 football pitches), highlighting land availability as one of the most significant practical constraints. How many developable 200-to-500-hectare sites exist across the UK, and how many of these are close to demand, routes to market, power, water and biogenic CO₂, and ideally under a single landowner? Initial GIS mapping has begun to identify the sweet spots in Scotland where these conditions converge.

At full buildout, wind and Energy Hub projects are estimated to require around 54,000 full-time workers to operate, maintain and manage the clean fuel production systems created. When the clean fuels produced displace fossil fuel the resulting carbon emissions could exceed 27 Mt CO₂ per year.

Clean fuels will be required in both gaseous and liquid form, but large-scale Gaseous Hub archetypes are dependent on enabling infrastructure.

Gaseous pipeline infrastructure such as Project Union 2 and 3, and the Hydrogen Backbone Link (HBL) will not be commissioned before 2035. Therefore, early enabling capacity for those routes to market would likely begin only two to three years before that, with initial deployment focused on hubs such as Aberdeen and Northeast, Ayrshire and Chapelcross, while Grangemouth prepares to receive gaseous hydrogen for conversion. In the near term, it is anticipated that demand will be driven mainly by liquid fuels.

Further information on the long-term build-up of hydrogen production in Scotland, and what will be required to achieve it, can be found in “Energy Hubs Phase 2 Public Report Part 3: Fill the Backbone”.

To achieve a post 2035 build out:



Ahead of 2035, a Clean Fuels 2040 Mission should be established and refreshed in line with the latest SSEP, RESPs and LESP. The Green Book business case should also be updated to reflect the latest GDP and socioeconomic projections.



The 2040 Mission should take account of the latest position on HAR, if it remains in place, alongside the latest market development directives and mandates. It should also reflect the latest and projected energy pricing. One objective for the 2040 Mission could be to achieve subsidy-free clean fuels.



Energy Hub buildout capacity plans should be reviewed against actual progress in developing hydrogen pipeline infrastructure, including PU2, PU3 and HBL, as well as CO2 gathering networks. This should include both pipeline and non-pipeline transport options, such as vessel transport through ports.



Further energised land auctions should be progressed and broadened to include physical private wire options, i.e. a Wind-to-Molecule ScotWind Round 2.

Main barriers and enablers facing Energy Hubs

The key enablers for Scottish Energy Hubs, and for a wider Clean Fuels 2035 Mission, are rooted in Scotland’s natural capital. Its world-class wind resource, land, water, coastline, ports and pipeline routes provide the physical foundations for large-scale clean fuel production. These strengths are reinforced by the opportunity to turn constrained renewable power into lower-cost clean fuels, create alternative routes to market through private-wire and behind-the-meter arrangements, and stimulate demand through clear clean fuel mandates for aviation, marine and other sectors.

Other important enablers include the potential to blend liquid clean fuels, such as e-methanol, into existing fuel systems; policy mechanisms, such as the Clean Industry Bonus, to build domestic supply chains; the development of hydrogen transport and storage infrastructure for dispatchable power; access to biogenic CO2 through the Scottish Cluster and wider UK CO2 networks; and the use of Hydrogen Allocation Rounds to support early production and market formation.

The main barriers are rooted in fragmented market structures, policy uncertainty and delivery risk. Developers remain reluctant to take project-on-project risk across the full wind-to-molecule chain, while political uncertainty, concerns about subsidy leakage, and delays to whole-system planning are all slowing coordinated action.

Network ownership models and regulated asset incentives currently favour electricity transmission buildout, even where molecule-based solutions may offer better whole-system value.

At project level, developers face major challenges securing energised land, grid connections, offtake certainty and investment confidence. High UK electricity prices, slow policy decisions, onerous subsidy requirements, long connection timelines and limited support for end-user conversion costs all add to the difficulty. Taken together, these barriers could prevent Scotland’s clean fuel potential from translating into projects at the pace and scale required for net zero.

Policy and Regulatory Barriers, gaps and enablers

Targeted action on planning reform and essential policy and regulatory changes must be central to the Clean Fuels 2035 Mission.

The policy and regulatory landscape affecting clean fuels production is complex, spanning multiple Governmental departments and a mix of devolved and reserved powers. Hydrogen and Clean Fuels production projects must navigate multiple overlapping consenting regimes, without a dedicated home in planning and energy law.

Several specific policy gaps need to be addressed. However, what is needed most is a clear overarching strategy and leadership that considers:

 A whole-system approach to decarbonisation addressing both electrification and liquid fuels is essential.

 Delivering the required changes quickly will be challenging: Energy Hubs sit at the intersection of infrastructure and energy, both of which are typically slow and difficult to change. Once spatial planning decisions are made, they can be hard to revisit because of sunk costs and locked-in processes.

 Clear leadership, fast-tracked policy change and political recognition of the urgency of the challenge.



A mission that transcends Government Departments can achieve this.

Following the Clean Power 2030 model, Clean Fuels 2035 should sit within DESNZ and be led by a Mission Controller reporting to the Secretary of State for Energy Security and Net Zero. This new Mission Control should be tasked with delivering on targets for affordable drop-in clean fuels by 2035 and with setting the foundations for subsequent five-year missions through to 2050. The Mission should cover both biofuels and low-carbon hydrogen, with an overarching remit that cuts across multiple government departments. It should bring together a top team of industry experts and officials to troubleshoot barriers, negotiate solutions, and clear the way for investable, demand led energy solutions.

Theme	Barrier or Challenge	Policy solution or recommendation
Enable private wire and behind-the-meter arrangements.	Electricity Act 1989 / Order 2001 Exemptions: Current licensing and exemption thresholds make it difficult for large renewable generators above 100 MW to supply electrolyzers or other Power-to-X facilities through private wire arrangements, forcing many projects towards grid connection, licensing complexity, delays and additional system costs.	Reform the Electricity Act / exemption framework: Raise or tailor exemption thresholds to exempt private wire for generation if used for Power-to-X, to enable larger-scale private wire or behind-the-meter arrangements between wind generation and electrolysis.
A national CO2 utilisation strategy is required	Government policy and strategy on CO2 currently focuses on capture and storage and on engineered removals, rather than on utilisation. Without a clear national strategy, investors in e-fuels face uncertainty over long term CO2 access, pricing, and eligibility in mandates and business models. A national CO2 utilisation strategy will help ensure that CO2 is transported and used in the most efficient way - for example, by facilitating shared transport, storage and offtake infrastructure that serves both sequestration and e-fuels production. However, without clear priority rules for CO2 utilisation and storage, there is a risk of unintentionally incentivising the wrong outcomes.	Create a UK CO2 Utilisation Strategy to secure sustainable biogenic CO2 feedstock for e-methanol, e-SAF and other clean fuels.
Planning and consenting	Planning could be a significant challenge- particularly where there are multiple landowners. Scotland's multi layered planning regime makes it structurally difficult to get consistent decisions on critical energy and infrastructure projects across 34 different planning authorities, even with a national framework like NPF4 in place.	Streamline planning and consenting for Strategic Projects within the Clean Fuels Mission: A master plan and a streamlined, consistent process for planning and consenting projects designated as Strategic Projects within that master plan could help accelerate deployment. CF35 should be formally recognised by NESO and embedded into the Enduring Strategic Spatial Energy Plan (SSEP), Regional Energy Spatial Plans (RESPs) and Local Energy Spatial Plans (LESPs)
Carbon leakage	UK Carbon Border Adjustment mechanism (CBAM) will cover hydrogen and ammonia but not e-methanol or refined fuels, meaning UK-produced clean fuels could be undercut by higher-carbon imports unless the CBAM is extended or equivalent support is introduced.	Investigate options / mechanisms for addressing carbon leakage to help UK-produced finished transport fuels be competitive against imports. Explore mechanisms by which CBAM scope may be extended to include imported fossil transport fuels whilst mitigating excessive impact on the price of refined fuels in the UK.

Theme	Barrier or Challenge	Policy solution or recommendation
Electricity Cost: Electricity is the biggest cost driver for electrolytic hydrogen.	Wind power directly coupled to load following electrolysis will provide a “Grid Relief” service to the UK Transmission Network by effectively ensuring the load impact of the wind farm output does not hit the Transmission Network, via a Behind-the-meter solution or by only using a short section of the Transmission Network via a “Private Wire” solution within that Transmission Boundary Region. This removes existing / future constraint at the point of curtailment, thus obviating the need to invest in Transmission HDVC links from Scotland to England, but this system value is not currently monetised. Existing mechanisms (e.g. CMP440) are limited in scope and time.	Introduce an availability-style payment that applies to “Behind-the-meter” and “Private Wire” arrangements: so that Energy Hubs could be paid via an availability-style payment per MWh consumed. Continue engagement with NESO to formalise this within constraint management frameworks.
	The British Industry Supercharger (BIS) provides a significant rebate for energy-intensive sectors to bring UK electricity costs in line with international competitors. Electrolysis projects qualify for the BIS scheme, which from April 2026 provides a 90% discount on electricity network charges (TNUoS, DUoS, BSUoS). Longer term certainty is needed.	Provide longer term certainty to investors: Supercharger and CfDs must give a low £/MWh and a contract length of 20 years to make Power-to-X investable.
	Administrative burdens, for example: The UK Low Carbon Hydrogen Standard (LCHS) requires hydrogen to have a lifecycle greenhouse-gas emissions intensity of no more than 20 gCO₂e/MJ (LHV)* in order to be classified as low-carbon hydrogen. The main source of carbon is the supplied power. Currently mandated that UK-wide grid carbon intensity is used to assess the hydrogen’s carbon intensity. This disadvantages Scottish projects, where actual local grid intensity is much lower. *Note: This carbon intensity figure applies to the hydrogen product rather than directly determining the lifecycle emissions. Performance of downstream derivatives such as e-methanol or e-SAF, which are assessed under their own applicable fuel-specific rules and methodologies.	Permit the use of regional grid emissions intensity values instead of national averages: Allowing projects to use local carbon intensity - or directly linking electrolysis to renewable generation - would avoid unnecessary shutdowns during high-carbon periods and reduce costs.
	Administrative burdens, for example: Under UK Low Carbon Hydrogen Standard (LCHS), hydrogen producers are typically required to retire (cancel) Renewable Energy Guarantees of Origin (REGOs) to prove renewable electricity use and avoid double counting environmental benefit. Implementation of Clean Power 2030 will make this a moot point by the time any Energy Hub capacity is deployed. LCHS requires strict temporal correlation requirements (30-minute matching). Again, this is an unnecessary level of administrative burden given Clean Power 2030 and UK’s rollout of renewables	Reduce administrative burdens: Remove or relax REGO requirements for hydrogen production facilities. Replace half-hourly matching with periodic compliance audits of power sourcing arrangements (could be 1-2 per year).
Demand side support - Longevity and confidence	Policies need consistency and longevity to secure investor confidence – For example, the RTFO and SAF mandates are key enablers which provide demand side support.	Provide longer term certainty to investors: To allow investment in projects with long (e.g., 20 years+) payback periods, an extension to the mandates beyond 2040 is needed. Similar Sustainable Marine Fuel Mandate should be introduced.

Conclusion

A network of Energy Hubs could convert Scotland’s constrained renewable resources into affordable, home-grown clean fuels, creating a practical route to market for stranded wind, reducing reliance on imported fuels, supporting industrial renewal and high-quality jobs, and providing the foundation for a resilient UK clean fuels sector.

Scotland has the natural capital and industrial platform to host these hubs, but delivery by 2035 depends on early enabling projects, streamlined regulation, lower-cost power arrangements, and strong central leadership capable of coordinating across planning, networks, markets, and end-use demand. The UK should move from fragmented project-by-project development to a coordinated, mission-led programme of action.



The UK should complement Clean Power 2030 with a Clean Fuels 2035 Mission, recognising that electricity alone cannot deliver full decarbonisation, energy security, affordability, and a Just Transition.



Drop-in fuels (such as e-SAF, e-methanol, e-diesel and biofuels) should be prioritised in the near term, as they offer the fastest and least disruptive route to decarbonising aviation, shipping and heavy transport.



Scotland’s constrained wind resource should be turned into economic value through a network of “wind-to-molecule” Energy Hubs. These hubs would produce drop-in clean fuels at points of grid congestion, rather than relying solely on increasingly expensive HVDC links to move electrons.



Detailed modelling indicates that e-fuel production can be commercially feasible in Scotland. The Shetland based model demonstrates the importance of selecting the right location, optimising the process and putting the right policy framework in place. This tailored mathematical modelling approach should be applied to other potential e-fuel production sites.



Six high-priority Energy Hubs, supported by five medium-priority hubs, should be the initial focus, collectively targeting around 10 GW of wind-coupled electrolysis by 2035 and building towards 40 GW by 2050 to meet NESO’s Holistic Transition demand for electrolytic hydrogen-derived fuels.



Targeted policy and regulatory reform is essential. This includes enabling private-wire and behind-the-meter-wind-to-electrolyser connections, embedding Energy Hubs in NESO’s strategic and regional spatial plans, extending certainty around RTFO/SAF mandates, and creating a UK CO₂ utilisation strategy so domestic e-fuels can compete with imports and avoid stranded assets.



This Clean Fuels 2035 Mission should set the foundations for a series of five-year Clean Fuels Missions through to 2050, to scale capacity progressively.

Abbreviations

Abbreviation	Definition
B6	Anglo-Scottish transmission boundary
BIS	British Industry Supercharger
BSUoS	Balancing Services Use of System
CAPEX	Capital expenditure
CBAM	Carbon Border Adjustment Mechanism
CCS	Carbon capture and storage
CfD	Contracts for Difference
CF35	Clean Fuels 2035
CO2	Carbon dioxide
COD	Commercial Operation Date
CP2030	Clean Power 2030
DESNZ	Department for Energy Security and Net Zero
DUoS	Distribution Use of System
EGL2	Eastern Green Link 2
FID	Final Investment Decision
GDP	Gross Domestic Product
GIS	Geographic Information System
GW	Gigawatt
HAR	Hydrogen Allocation Round
HBL	Hydrogen Backbone Link
HMT	His Majesty's Treasury
HVDC	High-voltage direct current
LCHA	Low Carbon Hydrogen Agreement
LCHS	Low Carbon Hydrogen Standard
LESP	Local Energy Spatial Plan
LHV	Lower Heating Value

Abbreviation	Definition
MJ	Megajoule
MtCO2	Million tonnes of carbon dioxide
mtpa	Million tonnes per annum
MW	Megawatt
MWh	Megawatt hour
NESO	National Energy System Operator
NPF4	National Planning Framework 4
NZTC	Net Zero Technology Centre
NZTTP	Net Zero Technology Transition Programme
OEM	Original equipment manufacturer
OPEX	Operating expenditure
PPA	Power Purchase Agreement
PU	Project Union
REGO	Renewable Energy Guarantee of Origin
RESP	Regional Energy Spatial Plan
RTFO	Renewable Transport Fuel Obligation
RTM	Route to Market
SAF	Sustainable Aviation Fuel
SSEP	Strategic Spatial Energy Plan
SWOT	Strengths, Weaknesses, Opportunities and Threats
TNUoS	Transmission Network Use of System
TTM	Think Tank Maths
TWh	Terawatt hour
UK	United Kingdom

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Technology Driving Transition

Contact number:
+44 (0)1224 063200

Media enquiries:
pressoffice@netzerotc.com

Net Zero Technology Centre
W-Zero 1, Energy Transition Zone,
Hareness Road, Aberdeen AB12 3LE

www.netzerotc.com

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