Beyond Electricity

Nuclear energy's role in supporting industrial decarbonisation and economic growth on Teesside and beyond.

Results of 2023 Independent Research Commissioned by X-energy

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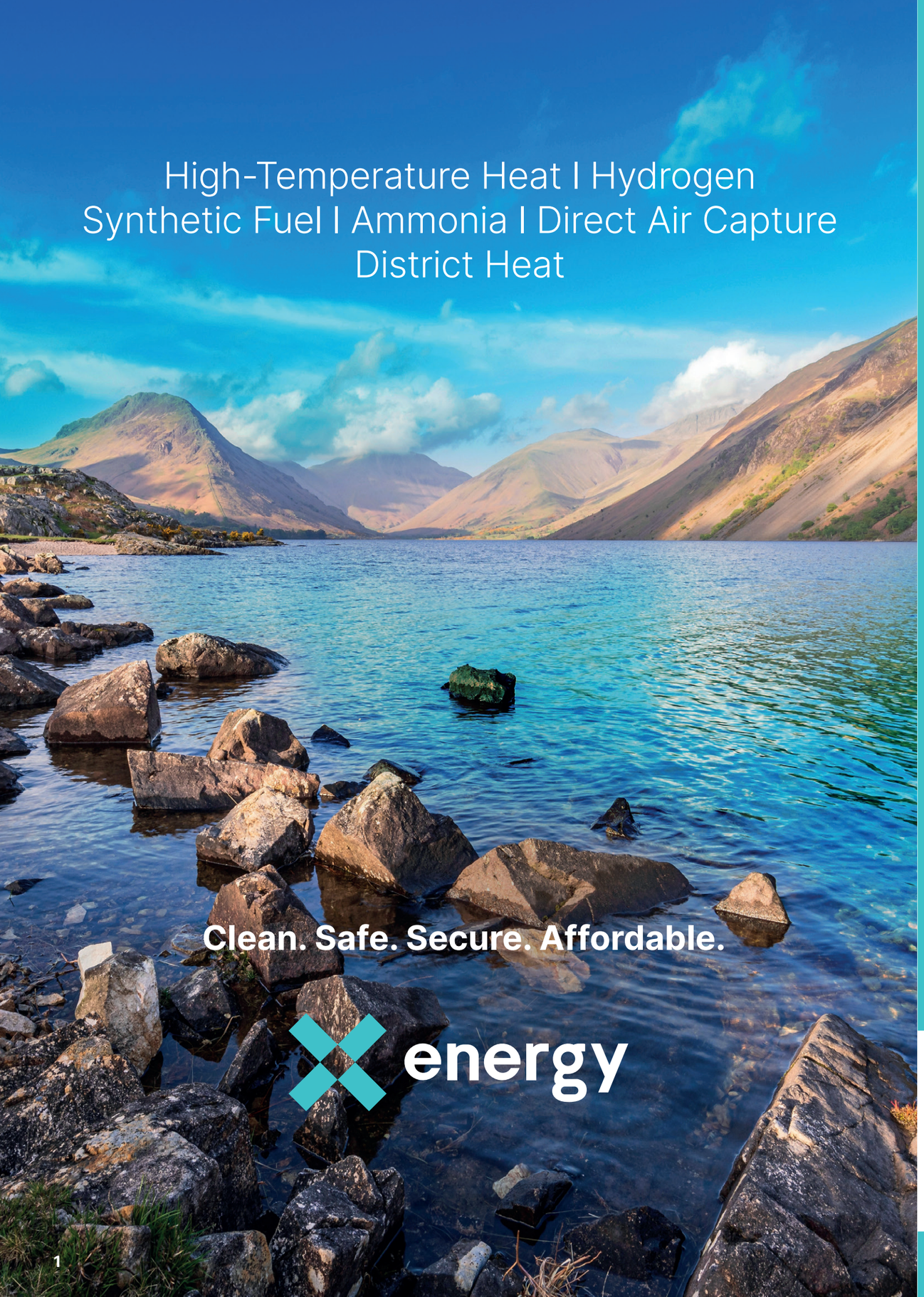

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Foreword

The need for nuclear power as part of our current and future energy mix is widely understood, but its role in securing affordable supplies, tackling climate change and boosting economic growth does not stop at electricity.

Electricity use currently produces less than a quarter of the UK's annual carbon dioxide emissions. Transport and industrial heat together represent more than twice the amount, and are harder to tackle. We need to take on these big, hard-to-abate, sectoral challenges in a way that protects and creates highly-skilled jobs and growth in the United Kingdom.

X-energy's high temperature gas-cooled reactor blends innovation with tried and tested technology. It can support the challenging target of 24 gigawatts of nuclear electricity by 2050, including flexible generation to complement renewables, but it can also produce valuable steam at higher temperatures, with more applications, than traditional nuclear technologies.

We intend to deliver up to 10 four-reactor power plants across the UK, starting with a multi-billion-pound investment in Hartlepool.

The industrial heartland of Teesside has a major demand for high temperature heat and steam. Sourcing this from the Xe-100 can support the future of clean process industries, contribute to a growing hydrogen economy and boost the manufacture of net zero fuels for aviation and shipping. These technical innovations can bring long-term, high-quality jobs and create a global leadership position for Britain.

We plan to have our first project up and running in the early 2030s. We have partnered with leading experts Equilibrion to assess the opportunity for heat applications, beginning at Teesside. This report summarises initial work which we are building on to underpin our proposition to customers and policy makers. We hope you enjoy the report, and we look forward to working with UK companies, community representatives and other stakeholders as we turn this huge opportunity into a reality.

Thank you very much,

Carol Tansley
Vice President, UK New Build Projects
X-energy

Equilibrion is a specialist consulting and project development company with leading expertise in the role of nuclear energy for the decarbonisation of transport, industry and production of clean fuels. Our experience spans policy, technology, strategy, techno-economic assessment and commercial project development.

We are delighted to have applied our varied experience to deliver the evidence base that supports this document and are proud to be supporting the role advanced technology can play in achieving net zero.

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Executive Summary

Our assessment concludes that nuclear-enabled high-temperature heat and steam is a realistic opportunity for the decarbonisation of process industries and as a feedstock for new zero-carbon products.

- The Xe-100 has a range of deployment opportunities in addition to generating clean electricity, for example producing hydrogen, ammonia, synthetic fuels for aviation, carbon capture, desalination and district heating
- X-energy has so far identified dozens of potential users of the Xe-100 energy output on Teesside where the system output could meet demand scale and profile
- The opportunity for decarbonisation through the provision of direct process heat and steam could justify multiple reactor deployments on the Hartlepool site
- The Xe-100 has a key value proposition for the production of hydrogen on Teesside at scale. This would align with current hydrogen production ambitions in the region, the potential hydrogen network and the existing storage infrastructure
- Access to CO2 storage and transportation facilities could provide the opportunity for the Xe-100 to enable electricity to technologies that can remove CO2 from the atmosphere and contribute to reducing the effects of climate change through negative emissions
- Opportunities on Teesside would be complementary to, not in competition with existing net zero infrastructure developments
- There is clear additional opportunity for delivering domestic and low-grade heat decarbonisation through current and future district heating networks. Flexible electricity supply from the Xe-100 can compensate for the variability of renewables connected to substations in the area
- Access to low-carbon electricity and heat can support the growth of synthetic fuel production on Teesside and across the UK to meet the net-zero targets of Teesside International Airport, amongst other industries requiring low carbon fuels
- X-energy is further developing the evidence base for heat applications of nuclear energy to build its value proposition and identify specific deployment opportunities
- This work will continue to focus on Teesside but also pave the way for wider UK deployment both in industrial clusters and areas of more dispersed industry.

The Xe-100: High Temperature Heat and Power

The Xe-100 is a high-temperature gas-cooled reactor (HTGR) offering 200MW of thermal power, or 80MW of electricity. Deployment of four Xe-100 reactors is already progressing in the US in partnership with Dow.

X-energy's first project is due to come online in 2029 at Dow's Seadrift industrial complex to provide heat and power concurrently.

In the UK an Xe-100 fleet would contribute to the Government's ambition to deliver 24GW of nuclear capacity by 2050. A target has been set by X-energy that at least 80% of the components for the Xe-100 are manufactured in the UK. This high level of UK content will create and sustain thousands of highly skilled, well-paid manufacturing and construction jobs across the country.

The Xe-100 is proposed to be delivered in the UK by the early 2030s in packs of up to four reactors, providing:

- Up to 320MW of clean, flexible and affordable electricity;
- Up to 800MW of low-carbon high-temperature heat (greater than 500°C) or;
- a combination of the two.

This combination provides for the needs of today's industries, but also those that must emerge on the path to net zero. Example applications where the Xe-100 can support net zero compliance include industrial heat and electricity for chemicals manufacture, hydrogen production, steelmaking, glass and paper production, ammonia manufacturing and sustainable aviation fuel synthesis.

The reactor benefits from modular construction and uses snooker ball sized fuel 'pebbles' described as the "the most robust nuclear fuel on Earth", by the US Department of Energy. Having been pioneered in the UK during the 1960s, the TRISO particle fuel has operated in similar reactor designs in the USA and Germany. These reactors generated electricity for over 20 years and other TRISO fuelled reactors are operating today.

In 2023, X-energy commissioned Equilibrion to establish a solid platform of evidence for decarbonisation of UK industry with the Xe-100, using the Teesside Industrial Cluster as a case study. The study looked at a range of decarbonisation opportunities, considering current decarbonisation plans, specific temperature requirements, infrastructure access and availability, the relative locations of energy demand, and specific temperature requirements.

Described by the US Government as "the most robust nuclear fuel on Earth"

Policy & Economy

High-Temperature Gas-Cooled Reactors are recognised by the UK Government as offering decarbonisation opportunities right across our energy system, including in areas where there are few or no alternatives to fossil fuels.

Net zero policies for energy-intensive sectors such as industry, aviation, home heating and transportation all refer to how modern nuclear technology can support net zero through the provision of direct industrial heat, district heating, hydrogen and sustainable aviation fuel.

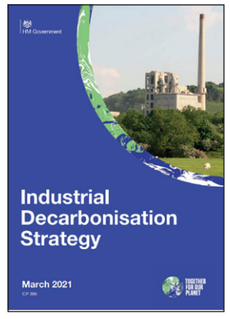
Through intermediate products, energy users can access the low-carbon energy that nuclear can provide to support their transition to net zero. For nuclear operators this provides routes to market that have never before been available. The Hydrogen Business Model and proposed Sustainable Aviation Fuel Mandate include nuclear energy as a qualifying energy source providing the option for game-changing opportunities to accelerate the clean energy transition.

UK government policy is providing nuclear energy with new routes to market to deliver game-changing decarbonisation solutions

Industrial Decarbonisation Strategy

"This potential (of advanced reactors) to produce high temperature heat can be used as an alternative to fossil fuels in industrial processes"

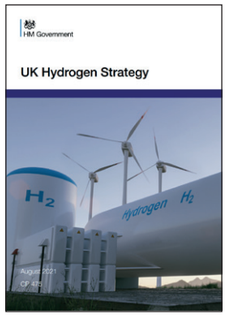
Department for Energy Security & Net Zero



Hydrogen Strategy

"in the future... advanced modular reactors could facilitate greater deployment and use of nuclear-derived heat and power in high temperature electrolysers"

Department for Energy Security & Net Zero



SAF Mandate Consultation

"SAF from nuclear energy... will be allowed where renewable or nuclear electrolytic hydrogen is combined with waste CO2,the resulting fuel will be eligible for PtL certificates"

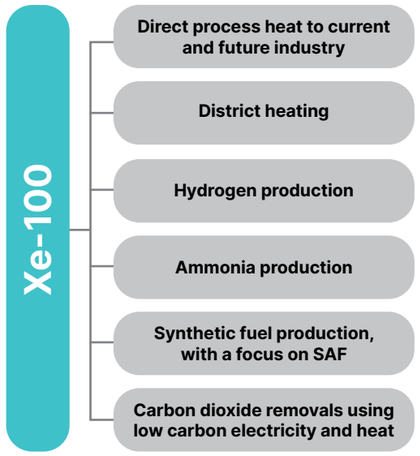
Department for Transport

Through its inherent versatility, the Xe-100 can meet the needs of industrial energy users through a consistent and reliable supply of heat and electricity in places other reactor technologies cannot reach.

The Xe-100 operates at temperatures in excess of 750°c with steam temperatures of 565°c. This heat can be converted to a range of low-carbon energy vectors and products using conventional technologies.

A flexible powerhouse, UK deployment of the Xe-100 will increase security of energy supply and meet the needs of industries, modes of transport and the homes of today and tomorrow. By operating at higher temperatures compared to other nuclear technologies, the Xe-100 has the ability to meet a wider range of industrial process temperature needs, delivering decarbonisation where other reactor technologies cannot reach. The higher temperature also improves production efficiencies reducing the cost of energy to consumers.

The Xe-100 can also deliver flexible output to reflect changing energy demand by managing heat and energy flows.



The Xe-100 can deliver flexible electricity to complement renewables

High temperature process heat	Direct and consistent provision of secondary steam and heat transfer fluids
Hydrogen	High-temperature, lower-cost hydrogen production
Flexible electricity	Management of heat and energy flows to reflect changing energy demand and complement renewables
Synthetic fuels for transport	Stable electricity, heat, hydrogen production and carbon capture to maximise utility of fuels production and complement renewables
District heating	Energising of district heat systems using excess heat at low cost
Ammonia	Using high-temperature heat and electricity to ensure fertiliser supply, security and optionality for low carbon shipping
CO2 capture	Providing heat and electricity to direct air capture systems that reduce the levels of CO2 in the atmosphere

Case Study:
The Teesside Industrial Cluster

Decarbonisation and development of low carbon industry is a major priority for Teesside with clear targets and objectives for industrial decarbonisation and growth.

Teesside is one of the UK's six highest polluting industrial clusters and is also home to an operating nuclear power station. It is unique in the UK as an industrial heartland already familiar with nuclear technologies. This is why the Teesside cluster was selected as the case study for this research project, which also considered how this area could be a blueprint for other UK regions.

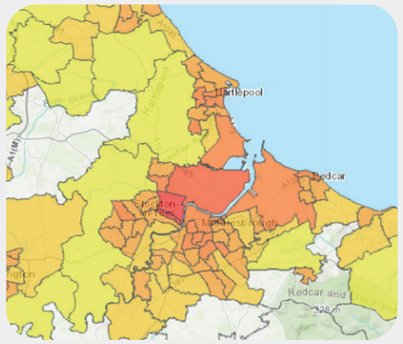
In 2019 the Teesside cluster emitted 6.9 million tonnes of CO2 to the atmosphere. 63% (4.3 million tonnes) of these emissions came from industrial sources, with the region accounting for 5.5% of the UK's total industrial emissions.

The cluster has a broad range of energy needs from solely electrical demand to high-grade heat over 600°C. Most industries require a range of electrical and heat inputs at a variety of temperatures. Meeting this variable demand in new, low-carbon ways, is one of the most challenging and disruptive aspects of achieving net zero before 2050.

Teesside is already a strong advocate of decarbonisation and net zero solutions with a target of being the first net zero cluster by 2040 and to be a producer of 5GW of low-carbon hydrogen by 2030. Current decarbonisation projects can be augmented by additional access to the low-carbon energy from nuclear, which can also attract new businesses to support today's fossil-intensive industry transition to low-carbon operations.

Teesside has a significant heat demand, centered on the industrial cluster for process heat and domestic properties and business that require lower temperature heat.

The figure shows the distribution across the region and identifies the potential addressable market for the Xe-100.



Annual aggregated heat demand within a geographical area (MWh(thermal)/km2)

- 1,000 - 2,000
- 2,000 - 10,000
- 10,000 - 20,000
- 20,000 - 100,000
- 100,000 - 200,000
- > 200,000

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Introducing
the Teesside Cluster

Industries on Teesside include:

- Steel forgers
- Food and drink producers
- Ammonia and fertiliser producers
- Pharmaceuticals
- Biofuel producers
- Chemical producers
- Polymer producers
- Catalyst manufacturers

Teesside Characteristics	Value
Annual Emissions (2019)	**6.9 million tonnes**
Annual Industrial Emissions (2019)	**4.3 million tonnes**
Tees Valley Combined Authority Population	**680,000**
Net Zero Target Date	**2040**
Low Carbon Hydrogen Production Target	**5 GW by 2030**

The Role of X-energy on Teesside

"Hartlepool is a natural choice for building the next generation of gas-cooled reactors, the Xe-100."

X-energy has identified the land adjacent to the existing Hartlepool nuclear site as an ideal location to deploy its first 12 reactors in the UK, within the Teesside industrial cluster.

The current Advanced Gas-cooled Reactors at Hartlepool began operating in 1983, and are currently scheduled to retire in 2026, with the land around the existing plant having been designated for nuclear new build since 2008. This, combined with an experienced workforce and supportive community, means Hartlepool is a natural choice for building the next generation of gas-cooled reactors, the Xe-100.

The study identified how the Xe-100 can meet local needs through specific energy applications, as shown below:

Application	Teesside Local Needs	How the Xe-100 can support decarbonisation
High temperature process heat	Multiple industrial users of process heat including petrochemical and manufacturing industries	Provision of constant high-temperature heat at up to 750°c (steam up to 565 °C)
Hydrogen	Domestic and industrial demand for flexible heat through hydrogen, including the development of a local hydrogen grid	Heat-assisted hydrogen production can deliver higher efficiencies than conventional technology
Flexible electricity	Increasing variable capacity from offshore renewables requires demand matching for industrial use	Flexible energy through rampable power output or demand switching with hydrogen production
Synthetic fuels for transport	Existing oil and gas infrastructure used to produce refined petroleum products	Production of zero-carbon feedstocks for synthetic clean fuels
District heating	Local residential home heating and commercial shared heating schemes	Provision of excess heat at a low cost to energise district heating networks
Ammonia	Fertiliser production locally needs to decarbonise	Application of heat to improve the efficiency of green ammonia production
CO2 capture	Teesside is a leading location for deployment of CCUS technology	Improvements in the efficiency and cost of CO2 capture with constant heat and electricity

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Addressing the UK-wide Opportunities

Teesside is just one of the UK's six industrial clusters, the study also considered how the Xe-100 could address wider system decarbonisation.

The clusters together account for half of UK industrial emissions and of this, approximately 70% of industrial energy demand is heat, with around 35% of this demand from steam systems alone. The remaining half of emissions are from dispersed sites. These present different challenges and diverse solutions to deliver decarbonisation with the Xe-100.

Energy demand, local infrastructure, existing decarbonisation plans and specification of heat required were all considered, both in clusters and dispersed UK industrial sites. This includes decarbonising the industries of today and tomorrow, for example, low-carbon hydrogen and synthetic fuel production.

"70% of UK industrial energy demand is for heat"

The UK's Industrial Clusters (Total 37.6MtCO2e)

The study highlighted options for siting based on proximity to heat demand within and beyond the current clusters of Teesside, Humberside, Merseyside, South Wales, Grangemouth and Southampton. In these locations, the study showed that the quantity and type of heat demand could justify multiple deployments of the Xe-100.

Furthermore, the importance of delivering 24/7 electricity and heat cannot be overstated and working in synergy with other technologies, for example, carbon capture and renewable electricity, can provide both optionality to energy users and an ideal approach to delivering meaningful large-scale decarbonisation.

The UK's Dispersed Sites (Total 33.5MtCO2e)

Dispersed sites are facilities located more than 25km from the UK's six clusters. These account for approximately half of the UK's industrial emissions and include users with a range of demands.

Where the demand at dispersed sites falls below the output of an Xe-100, there are opportunities for flexible electricity supply to the national grid and utilising excess heat to produce low-carbon fuels and hydrogen. The potential for decarbonisation with the Xe-100 is further augmented by the opportunity for excess, lower-temperature heat to energise district heat networks; a priority and challenging decarbonisation area for many areas of the UK.

THE NEXT STEPS (overleaf)

A Unique Opportunity for Teesside and Beyond

Next Steps

X-energy will:

- Augment the heat decarbonisation value proposition including an evidence-based proposition for hydrogen production, synthetic fuels and direct air capture on Teesside;
- Progress development of the value chain propositions that enable nuclear heat and electricity to be converted to the low-carbon energy products demanded by end users;
- Assess UK-wide deployment opportunities, focusing on energy demand, siting opportunities, infrastructure availability and existing decarbonisation options;
- Develop and set out a series of policy asks and recommendations for Government to capitalise on this opportunity.

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