Industrial Demand Flexibility

Research Priorities

UKERC Meeting Report

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The full list of workshop participants is provided in Appendix B.

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1. Executive Summary

Electrification will be central to the UK's decarbonisation efforts, but meeting the resulting electricity demand with a predominantly renewable powered grid will require greater system flexibility. Energy-intensive industries have significant potential to contribute to consumer-led flexibility (CLF) and other demand-side measures. However, to date, this potential remains under-researched.

This report summarises the findings from a recent expert workshop, where participants identified the key knowledge gaps and research priorities most critical to advancing industrial flexibility in Great Britain (GB). The top priorities focus on quantifying flexibility potential across sectors and regions; developing robust methods to assess economic feasibility and mapping the effectiveness of market incentives. In addition, establishing accurate data on peak industrial energy use was highlighted as an urgent requirement to support informed decision-making.

2. Industrial Flexibility: an Introduction

Electrification will play a significant role in enabling manufacturing industry to decarbonise. In its modelling for the UK's Seventh Carbon Budget, the Climate Change Committee found that electrification will provide 57% of all emissions reductions in 2040 (1). Meeting the increased demand for low carbon electricity will require greater system flexibility to manage seasonal peaks, offset variable renewable generation, and support additional loads from electrified heat and transport. Clean flexibility helps minimise the total system cost of a decarbonised electricity system, by making it more adaptable and efficient in managing supply and demand. It can take multiple forms, including CLF, battery storage, interconnection, long-duration storage, and low carbon dispatchable power (2). Scenario modelling indicates that the UK could have around 204 GW of clean flexibility capacity in 2050, with the industrial and commercial sectors' contribution rising from 0.8 GW in 2024 to 3.9 GW by 2050 (*ibid*).

Energy-intensive industries, by definition, have large loads and therefore significant potential to contribute to demand-side response (2). Currently, there are a number of markets that will pay industrial consumers to adjust their electricity consumption, including the Balancing Mechanism, Capacity Market, and the Demand Flexibility Service (3). Demand for flexibility services across these markets is expected to increase substantially in the coming years, meaning that industrial participation will become increasingly important. Yet research on the role of industrial flexibility in meeting this future demand remains limited. The barriers to participation, the mechanisms needed to incentivise it, and critically the benefits to industry itself, are not well understood. The sector is highly heterogeneous, meaning a one-size-fits-all approach is unlikely to succeed. In addition, electrification of industry (a necessary precursor to CLF) faces well-documented barriers (4). It is therefore important to identify the conditions under which increased volumes of flexibility could be delivered in ways that strengthen both system resilience and industrial competitiveness.

This report aims to begin to address this knowledge gap, focusing on CLF and behind-the-meter measures (such as on-site energy generation and electricity storage) in energy-intensive industries at the site level. It explores four themes: (1) how sector, technology, and product types might influence industrial flexibility provision; (2) the geographical distribution of industry and network headroom across GB and potential implications for flexibility; (3) the challenges of behind-the-meter measures; and (4) digitalisation and incentivising market entry. Across each of these themes, we are interested in understanding not only how flexibility can support the electricity system, but also how it can deliver clear and practical benefits to industry.

2.1 Sector, technology and product

CLF involves the voluntary shifting of electricity use away from peak periods to times when supply is more abundant. However, different industrial sectors will vary both in their future electricity consumption (5) and in their capacity to adjust energy use or production in response to system needs. Future electricity consumption will also be affected by how challenging a process is to electrify. In sectors using low-to-medium temperature heat, such as food and drink, electrification technologies are relatively mature and widely available. By contrast, many options for decarbonising high-temperature processes rely on novel uses of electricity that are at lower levels of technical maturity (6). Crucially, however, a process may be relatively straightforward to electrify, but the associated technologies may still be difficult to operate flexibly. Recognising this distinction is essential for understanding where genuine flexibility potential lies.

Capacity to adjust processes and products will also vary across sectors and is likely to evolve in the future. Some manufacturers may be more open to shifting load or reducing demand in return for payment, while operational constraints such as continuous or batch processing may mean others prioritise consistent output over cost savings or carbon reductions (7). In some sectors, quality and safety requirements for industrial products may make it difficult to alter operating patterns without extensive revalidation.

2.2 Geography and network headroom

Energy-intensive industry is unevenly geographically distributed. Steel is concentrated in South Wales, Yorkshire, and North-East England, while chemicals have major clusters in North-West England, Yorkshire and the Humber, Teesside, and parts of Wales. Mineral extraction is more dispersed, while glass, pulp and paper, and ceramics each have distinct regional bases. Lighter manufacturing, including automotive, engineering, and construction, is concentrated in major cities. This industrial geography matters for regional flexibility delivery, since the location of demand dictates where flexibility potential can be accessed. The picture is further complicated by geographically uneven network headroom (6). Regions with substantial headroom are less likely to require or procure flexibility services, whereas areas with limited headroom may become prime locations for procurement (7).

At present, it is unclear whether regions with the lowest headroom align with those that have the highest industrial flexibility potential, or whether a mismatch exists. In the latter case, some sectors and areas could be financially disadvantaged, unable to access new revenue streams by trading flexibility in energy markets. Where flexibility is deployed, it could help unlock additional capacity and shorten connection queues locally (8). Understanding these geographic and network dynamics will be crucial to ensuring that flexibility is deployed effectively and equitably across the system.

2.3 Behind-the-meter generation and storage

The deployment of distributed battery storage close to the point of consumption can support system flexibility by storing excess energy during periods of low demand or overgeneration, for example, when local solar PV output is high. This stored energy can then be discharged during periods of network constraint or to bridge gaps caused by intermittency (9). This can allow an industrial site to offer flexibility to the network without varying its production profile, as the on-site generation or storage acts as a buffer between the electricity demand required and the supply from the network.

There is a significant body of work on battery storage and solar PV in domestic settings. However, industrial facilities are less well studied, with most research concentrating on the economic case for battery storage (9, 10). Preliminary work for UKERC has identified additional operational constraints. These include: (1) site suitability and ownership, since not all industrial buildings are structurally suitable for rooftop solar, particularly older sites with fragile or asbestos roofs, while tenant-occupied buildings can face issues with landlord consent; (2) system complexity, as effective battery deployment requires detailed monitoring of operating patterns, alongside navigating grid connection and approval processes, which are particularly onerous for firms operating across multiple Distribution Network Operator (DNO) regions; (3) space trade-offs, where valuable floor area must be dedicated to batteries rather than production; and (4) workforce alignment, since maximising use of stored energy may require the introduction of shift work. Understanding these constraints will be vital to identifying the type of industrial sites that can contribute to CLF.

2.4 Digitalisation and incentivising market entry

Industrial and commercial levels of demand flexibility have declined since the end of the Triad charging regime (11). Unlocking industrial flexibility will require coordinated policy efforts across consumer support, infrastructure investment, land-use planning, and the strengthening of skills and supply chains (2). At the site level, energy digitalisation and incentives that enable market entry and participation will be particularly important for engaging energy-intensive industries in CLF.

Research for the Carbon Trust (12) suggests key barriers to non-domestic demand-side response include businesses' concerns that participation could disrupt core operations, which often outweigh the relatively modest financial gains on offer. While markets exist for providing flexibility, the potential rewards have not yet outweighed perceived operational risks, cybersecurity concerns over data sharing, and the upfront cost and time required to enable flexibility. These dynamics may shift as renewable penetration rises and price signals increase the value of flexible actions. Nevertheless, stakeholder acceptance is likely to remain a challenge.

Recent initiatives to address these issues include £36 million in the Modern Industrial Strategy (13) for Smart Data schemes, and ongoing regulatory reforms to the Capacity Market (14). Looking ahead, the National Energy System Operator (NESO) plans to drive greater non-domestic flexibility by setting clear targets for annual growth in large consumer participation by December 2025. By April 2026, NESO will explore options for carbon reporting, allowing industrial and commercial users to measure the carbon savings associated with their flexible energy use (2). Key questions include how effective the proposed reforms will be in addressing the identified barriers, enabling participation and delivering impact.

3. Methodology

To investigate these issues further, we held a one-day expert stakeholder workshop in November 2025 to discuss knowledge gaps and research priorities related to industrial demand flexibility across the four identified themes. The workshop explored the conditions under which energy-intensive industries can provide increased CLF, identifying operational, technical, and market barriers along the way. Its purpose was to clarify key knowledge gaps and inform a research agenda to guide policy, business models, and technology development.

Appendix A contains the guiding questions provided to participants, and Appendix B lists the workshop attendees.

4. Key findings

4.1 Knowledge gaps

The first session focused on identifying key knowledge gaps in industrial demand flexibility. Participants highlighted the difficulty of considering any of the topics in isolation and the importance of taking a whole energy system viewpoint. A number of cross-cutting themes emerged, highlighting areas of shared interest and concern.

What types of flexibility are there?

Discussions highlighted that industrial flexibility is not a single action but a group of distinct practices, each with its own constraints, dependencies and risks. Load shifting remains the most widely discussed form, in which the time and/or level of production is changed. This can occur implicitly, when companies autonomously adjust production in response to operational priorities or external energy price signals, or explicitly, when shifts are made in response to instructions from system operators.

However, for many operations, load shifting may not be possible without buffering, meaning the temporary build-up of product or semi-finished goods so that production can be paused without affecting delivery. This can introduce cost, storage and quality concerns, and requires trust and coordination across supply chains.

Beyond production adjustments, flexibility can also come from behind-the-meter interventions, such as on-site generation and energy storage, ranging from batteries to thermal stores. Workshop participants discussed charging storage when electricity is cheap and releasing heat or electricity at peak times. Such interventions could expand the range of sites that can offer flexibility to the wider electricity system without interfering with core production processes.

Several discussions addressed vector switching, that is, changing the energy carrier, such as switching between electricity, gas, hydrogen or biomass, as another form of system-level flexibility. This category also includes on-site renewables, hydrogen electrolysers, bioenergy or even small modular reactors, all of which can shift demand depending on whether they draw from or supply to the grid. Vector switching can relieve grid stress by allowing sites to adjust which energy vector they rely on at different times, although only certain processes or technologies can operate in this way. Finally, participants touched on sector switching, where industrial flexibility could interact with flexibility in the domestic sector through heat networks.

Different forms of industrial flexibility operate over different timescales and depend on different technical, organisational and economic factors. Because each form will require different operational levers, they raise different questions about technical feasibility, economics, supply-chain implications and organisational change. Any analysis or policy intervention must therefore be explicit about which type of flexibility is being addressed.

What are the conditions under which sites can offer flexibility?

Industrial sites are better able to offer flexibility when their processes, products, and organisational conditions allow operational changes without unacceptable cost or risk. Batch processes are generally more adaptable than continuous lines, which are difficult to pause or vary without jeopardising quality and throughput. Lower-temperature processes are also more readily electrified and therefore, in the short term, more likely to provide CLF than high-temperature, hard-to-electrify operations. A critical and less recognised factor is the cost and time associated with requalification: in highly regulated environments - such as aerospace or defence - any operational change can trigger requalification requirements that may make flexibility commercially unviable. By contrast, firms that do not face requalification and/or that serve customers demanding low-carbon products will have more incentive to electrify.

Firm size and site configuration also matter. SMEs and smaller sites may be more adaptable, although they may also face greater upfront cost barriers. Site-specific factors, such as the physical space needed for batteries or thermal stores, influence whether behind-the-meter storage is feasible. Within any one sector, differences in plant age and investment cycles will create substantial variation; older assets may be inflexible and costly to upgrade for flexibility purposes, whereas more modern equipment may be digitally controllable and compatible with flexible response.

Overall, the discussions suggested that the ability to deliver industrial flexibility was shaped not only by which sector or sub-sector a firm belonged to, but also and possibly more importantly, by what kind of business it was, how its processes operated, how its products were certified and what its customers demanded. The sites most capable of offering flexibility are those with controllable or batch-based processes, lower requalification burdens, compatible equipment, and the organisational willingness, or market incentives, to operate differently. Decision-making tools are needed to help industry understand whether flexibility makes sense for their operations.

What incentives exist?

Participants agreed that current incentives for industrial flexibility were complicated and often not well-understood, leaving many firms uncertain about what revenue streams exist and the benefits they could bring. Triads were mentioned as an example of a mechanism that, although imperfect, was predictable and transparent. By contrast, the current mix of volatile prices, shifting tariffs and rapidly changing ancillary service rules is seen as poorly aligned to industrial realities, where firms need to schedule downtime and plan production cycles months in advance.

This ever-changing market environment means many industrial actors, even large operators, lack understanding of flexibility options. In addition, firms do not always have the data they need to make decisions on electrification and flexibility, with data requirements differing across businesses, DNOs and other stakeholders. This data gap reinforces uncertainty and slows investment.

Beyond market design, network connection and charging arrangements were identified as further weakening incentives for flexibility. Under current charging methodologies, all but the most expensive network reinforcement costs for demand connections are socialised. This means firms have little incentive to connect to networks with inherent flexibility, and may instead choose to have the networks built to accommodate their full load.

In response, participants highlighted the need to map incentives across different flexibility services, including opportunities for revenue stacking. There was also a need to distinguish current misaligned incentives from what future market structures might require, in order to create a coherent incentive framework to support industrial CLF. Without greater clarity and long-term certainty, industries are unlikely to offer flexibility at the scale needed.

What are the interactions with other policy areas?

The discussions highlighted that the potential for industrial flexibility is closely linked with electrification and broader decarbonisation policies. Not all processes are equally suitable for electrification. Understanding which can feasibly shift from gas to electricity, and under what conditions, is a necessary preliminary step to understanding the potential for industrial CLF. Flexible demand response will interact with policy incentives and costs, including future Carbon Border Adjustment Mechanism obligations, carbon taxes, and Emissions Trading Scheme obligations. This will influence whether sites choose to electrify.

The discussion also explored the role of market and network mechanisms. Flexibility markets are primarily designed around generation, so their effectiveness for industrial demand-side participation is less clear, and incentives may sometimes work counter to decarbonisation objectives. For example, companies may seek grid upgrades, not to increase production, but to enhance asset value or future saleability. Behind-the-meter solutions, such as on-site storage, can reduce costs and enable more responsive participation, while connection constraints and network curtailments affect the practical delivery of flexibility.

What are some possible solutions?

This is a complex issue, and no single intervention will be sufficient to incentivise industrial CLF. However, there was general agreement that a combination of the following measures would assist. On the industry side, decision-making tools and knowledge maps were seen as essential for helping sites understand their technical and economic potential for CLF. Data sharing, including success stories and problem-solving forums, could build confidence and support learning in adopting flexibility measures. AI and automation were identified as key enablers to optimise energy drawdown, storage and power switching across sites and systems.

On the market side, aggregators could simplify participation for smaller users and SMEs, while a combination of mandates and incentives could provide both guidance and motivation. Tailoring flexibility products to different customer types, improving digital infrastructure, and establishing clear pathways for different flexibility services were also emphasised. International examples were highlighted as valuable sources of practical lessons for GB.

In addition to the cross-cutting knowledge gaps above, several key data gaps were also highlighted as critical for understanding and enabling industrial flexibility. These are summarised in **Table 1** below.

Table 1: Summary of key data gaps

Data gap	Description
Data and modelling	There is limited data on current and future industrial electricity demand, flexibility potential, and sectoral/geographical variations. Key uncertainties include peak energy use, the scale and timing of electrification, and the impact of different types of flexibility. This lack of granular data hampers the ability to model pathways for industrial CLF to 2050 and assess where CLF will be most valuable.
Market incentives and structures	The complexity of revenue stacking, ancillary service markets, and bilateral contracts is poorly understood, and current incentives are seen as insufficient to motivate adoption. Mapping these incentives and understanding their interaction with different forms of flexibility is required.
Decision-making and organisational support	Site operators need tools to evaluate the technical and economic potential of CLF. They also require guidance on operational constraints, revenue implications and optimal use of automation or storage. There is a broader need to understand the level of knowledge across industry.
Sectoral and technological suitability	Industrial processes, technologies and business models are highly heterogeneous, meaning flexibility potential will vary widely. There is a gap in understanding as to which processes, product types, and site configurations can reliably offer flexibility, and under what conditions.
Coordination and data infrastructure	Gaps exist in understanding how supply chains, inter-site coordination, and digital infrastructure can enable or constrain flexibility.

4.2 Research priorities

Drawing on insights from the first session, participants discussed their views on research priorities in the second session. The following longlist of research questions were proposed:

Group 1: Sector, technology and product

1. What factors are associated with the successful implementation of flexible working practices?
2. What does industry need in order to electrify?
3. Outside of clusters, who should be prioritised for engagement - who has the most potential?
4. What data is needed by NESO, DNOs, and businesses to enable companies to deliver CLF?

Group 2: Geography and network headroom

5. What is the flexibility potential from non-National Atmospheric Emissions Inventory dispersed sites, and can it be mapped across GB?
6. What is peak industrial energy use across GB by time of day?
7. What is the technical potential by sector and process, and how can this be mapped across GB?
8. Can we develop a methodology for calculating the economic flexibility potential across different regions?

Group 3: Behind-the-meter generation and storage

9. Can we quantify the potential capacity for flexibility, considering technical issues, regulatory hurdles, financial issues, and some of the internal company issues (e.g. company culture and strategy)?
10. How can high-temperature heat storage technologies, such as thermal batteries, be deployed as enablers of industrial flexibility, and what are their technical, economic, and process suitability considerations?
11. How will network flexibility contribute to wider energy security, for example in terms of critical raw material demand and network upgrades?
12. What lessons can be drawn from energy-efficiency programmes and international examples of successful flexibility initiatives?

Group 4: Digitalisation and incentivising market entry

13. Can we provide a typology of different types of flexibility vectors and when each should come online in time to meet strategic targets for 2030?
14. What incentives exist in current and future markets to promote access to flexibility, and how do they compare?
15. How sensitive are different customers to price signals under different scenarios and levels of participation?

Following this discussion, participants voted on the longlist of questions to identify their top three most important and top three most urgent research priorities. These are summarised in **Table 2**.

Table 2: Summary of ranked research priorities

Priority type	Top three research priorities
Most important	1. Calculate technical potential by sector and process, and map across GB
	2. Develop a methodology for calculating the economic flexibility potential across different regions
	3. Map incentives for current and future markets
Most urgent	1. Calculate technical potential by sector and process, and map across GB
	2. Develop a methodology for calculating the economic flexibility potential across different regions
	3. Calculate peak industrial energy use across GB by time of day

5. Conclusion

Industrial CLF has the potential to contribute to decarbonisation and grid resilience, provided key technical, organisational, and market conditions are met. Unlocking this potential requires addressing critical knowledge and data gaps, from mapping technical and economic flexibility to understanding market signals and peak energy use. As work progresses, there will also be a need to improve understanding of organisational behaviour, decision-making, and coordination across supply chains. The research priorities identified offer a clear starting point for action, laying the foundation for policies and strategies to enable effective, scalable industrial flexibility across GB.

6. Appendix A: Workshop Questions

Drawing on desk research and our previous work in the area, the following guiding questions were provided to participants:

Session 1: knowledge gaps

Group 1: Sector, technology and product

- Which sectors have high flexibility potential and which have low? Why?
- Which electrification technologies are inherently flexible, and which are not?
- Which sectors could deploy these technologies effectively?
- Which product types offer high or low flexibility potential?
- What gaps in knowledge or data do we have about sector/technology potential?
- Any other key knowledge gaps?

Group 2: Geography and network headroom

- How are flexibility opportunities distributed across GB, and how do they align with network headroom?
- Could network headroom act as a disincentive for deploying flexibility?
- Will some regions be disadvantaged by a lack of access to flexibility payments?
- What knowledge gaps exist about regional/systemic barriers?
- Any other key knowledge gaps?

Group 3: Behind-the-meter generation and storage

- What on-site resources could be used for flexibility (battery storage, on-site generation, diesel backup, other)?
- What practical barriers prevent industrial sites from participating in behind-the-meter flexibility (technical, operational, process-related)?
- How significant are the risks, including cybersecurity, production disruption, or reputational impacts?
- What knowledge gaps exist about operational or technical feasibility?
- Any other key knowledge gaps?

Group 4: Digitalisation and incentivising market entry

- What incentives are needed to encourage industrial demand-side response?
- Which market mechanisms or policies already exist, and how effective are they?
- Which business models are most attractive: cost savings, selling services to the ESO, or both?
- How can participation be simplified for SMEs and medium-sized industrial sites?
- What knowledge gaps exist about policy, market design, or business models?
- Any other key gaps?

Session 2: research priorities

Group 1: Sector, technology and product

- Based on opportunities and barriers identified, what are the key research questions for sector or technology deployment?
- What data gaps need addressing to understand sector/technology flexibility potential?
- Which product types require further study to evaluate flexibility potential?
- Any other key research priorities?

Group 2: Geography and network headroom

- What research is needed to map flexibility opportunities relative to network capacity?
- How should regional or systemic inequities be addressed in future research?
- Are there network or geographic factors that require further study to enable industrial flexibility?
- Any other key research priorities?

Group 3: Behind-the-meter generation and storage

- What research is needed to understand the feasibility of on-site flexibility measures?
- What operational or technical risks require investigation?
- What knowledge gaps could prevent wider deployment of behind-the-meter flexibility?
- Any other key research priorities?

Group 4: Digitalisation and incentivising market entry

- What research is needed to evaluate the effectiveness of existing policies and incentives?
- How can business models be designed to encourage uptake?
- What questions need answering to simplify participation for SMEs and medium-sized sites?
- Any other key research priorities?

7. Appendix B: Workshop Attendees

Name	Organisation
Lucy Adams	Electrify Industry
Peace Adesina	University of Leeds
Sian Allister	Cardiff University
Beth Barker	Aldersgate Group
Jessica Bays	UKERC
Frances Buckingham	DESNZ
Modassar Chaudry	Cardiff University
Carol Choi	UK Power Networks
Jon Flitney	Mineral Products Association
Ahmed Gailani	NESO
Arjan Geveke	Energy Intensive Users Group
Russ Hall	WMG, University of Warwick
Georgia Heritage	DESNZ
Olivia Johnson	Ofgem
Diana Khripko	University College London
Michael Lord	Climate Change Committee
Mateus Mendonca Oliveira	DESNZ
Duncan Oliphant	Northern Powergrid
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Imogen Rattle	University of Leeds
Jemma Rimmer	Ofgem
Viktor Salenius	NESO
Margi Shah	Cardiff University
Peter Taylor	University of Leeds
Jake Verma	University of Birmingham
Yingyi Wang	National Grid Electricity Distribution
Rachel Wiffen	Aluminium Federation

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