The Institution of Engineering and Technology

Energy

An Overview of Britain's Changing Energy Sector

What you need to know

www.theiet.org/energy

The 'old world' no longer exists; energy is already starting to change

The energy sector is extensive; it involves many parties, supports many functions and comprises complex dynamics between commercial, policy and technical landscapes. It is also undergoing an unprecedented change. At their core, the more static and centralised energy systems built last century are transforming into new flexible, sustainable and user-focused energy systems. Shaping this transition involves more stakeholders than ever before, many of whom are not energy specialists or are new to the energy sector.

In times of change, having a good view of the landscape makes all the difference for effective leadership and identifying new opportunities. To help stakeholders navigate some of the complexities of the sector, the Institution of Engineering and Technology (IET) brings together simplified explanations and forward-looking views in its series of energy sector Insight briefings.

Our briefings start from a practical engineering perspective before continuing to explore wider commercial, policy and social dynamics. There is a bias towards electricity, as these aspects have the potential to be key to interlinking the whole energy landscape. This complements other briefings published in the sector that primarily focus on policy, regulation and markets.

Key themes to master and the opportunities ahead

This first overview paper presents the breadth and complexity of the sector at a glance by setting out today's structure and highlighting key areas of change. We present insights aimed to help both realise and benefit from these changes. Using our Smart Energy Picture, described later, we identify six distinct **key themes that enable the reader to gain an overview of the sector changes:**

1 UNDERSTAND YOUR CUSTOMER: COMFORT, CHOICE AND ACCEPTANCE

The needs and wants of customers and society as a whole must be central to the activity of the energy sector in order for it to be fit for purpose. To ensure public acceptance, future supply should be as convenient, reliable, and low cost, as today's; with service providers offering choice, service and value for money.

2 DESIGN FOR FLEXIBILITY

The energy system as a whole must be agile and flexible to adapt to external change as it happens, with companies embracing opportunities as they develop. Resilience within this flexibility will enable safe and reliable supplies to be maintained.

3 USE NEW APPROACHES TO DRIVE SUSTAINABILITY AND EFFICIENCY

New approaches such as Demand Side Flexibility or local community energy can help support an energy system with significant levels of sustainable, but intermittent, energy sources; there are also opportunities to improve energy efficiency.

4 COLLABORATE ACROSS THE SECTOR FOR OPTIMISED SERVICES

Increasing collaboration across the energy sector is likely to bring significant advantages in optimisation for cost, carbon, and value. Gas, electricity, and heat networks already interact physically, and optimising this interaction would bring efficiency and resilience benefit. Collaboration with other sectors is likely to be valuable and enable offering of bundled services.

5 CO-ORDINATE AND COLLABORATE IN INNOVATION

Collaborating and aligning innovation across the whole energy system, and with other sectors, towards a shared longer-term strategy will mean that activity is efficient and focused. Significant effort is needed in innovation from early research and development through to deployment.

6 UNLOCK THE POWER OF DATA

Increased system visibility of the energy system is key for integrated and interactive energy management. Understanding what data is needed, and how it should be handled, is a key requirement. Sharing data across the sector is important to unlock its value, but data security is vital.

The Fundamentals of Britain’s Energy Sector

Figure 1: Main Categories of Energy Vectors

Electricity, either sourced from the national power network, or generated/stored locally

Combustible substances, including gases such as natural gas or hydrogen, liquids (e.g. oil, petrol), and combustible solids (e.g. wood, coal)

Heat carrying substances, e.g. water, steam, or air. These are used in space or water heating, and could be used for cooling

Common language used to describe the energy landscape

To appreciate the changes ahead it is helpful to first understand the fundamentals of the sector. These include Britain’s different types and sources of energy, how they are harvested, traded, transported and used and who are the key parties involved. Many of those aspects interact, but many are entirely independent.

Today, energy is delivered in a few key forms such as electricity, natural gas, and oil. These are termed ‘energy vectors’. There are several other vectors that could emerge more strongly in the future, e.g. heat or cold delivered by fluids such as steam or water and hydrogen or other combustible gases.

In general terms, energy vectors can be divided into three broad categories as illustrated in Figure 1 above.

Not all sources are directly suitable for being transported, while some sources of energy can be delivered in many different ways, e.g. oil. In general, any unit of energy will undergo the process steps shown in Figure 2 below, and it may be converted between multiple vectors before it reaches its destination.

These vector categories are explored in the following sections. Each section summarises their evolution over time, their key characteristics today and a forward outlook. These overviews are concluded with a final section summarising the drivers for change.

Figure 2: Process to Get Energy from Source to Use

Discovery and capture of energy source

Conversion to useful vectors

Energy transport

Energy storage

Conversion between vectors

Energy use

Cross-cutting topics include: information and communications, research, innovation and skills

Electricity

In Great Britain (GB), the established electricity supply systems have been built up over decades. Starting as many independent regional systems in the 1920s, it was not until the construction of the national grid network during the 1950s that they formed part of one electricity system. Progress in technology also enabled the construction of larger, more efficient power plants located outside city centres. 'Big is beautiful' was the credo that drove improved economics at that time.

Today, most of our electricity is still generated in large, centralised power stations and is moved around the country in bulk by transmission networks, managed by Transmission Owners (TOs). The former regional systems, now called distribution networks, serve the function of delivering this energy to the users. These networks are owned and managed by Distribution Network Operators (DNOs).

With little storage in the electricity system, there is a need to balance electricity generation and demand in real-time. The majority of this balancing is arranged in advance through trading of electricity by electricity suppliers based on expected price and demand. The residual second-by-second balancing of the system is managed by the GB System Operator (GBSO).

The evolution of GB's generation mix in recent years has been largely driven by stricter environmental regulation and societal awareness regarding carbon and air quality.

The generation mix is still dominated by fossil fuels, particularly in natural gas. There are increasing restrictions on the exhaust gases that can be released from large plant, and this is resulting in much of the coal generation being closed. Nuclear power is a significant contributor, providing over 20% of our needs. A growing share is delivered by renewable and low-carbon energy generation.

A rapidly growing type of generation is small-scale, usually renewable, connected to the distribution network. As the amount of this distributed generation increases, the flow of energy in the distribution networks will no longer be in just one direction from the transmission system to demand, but will be bi-directional and less predictable.

This is a fundamental change in the operation of the networks, with a number of technical and market implications, of which arguably balancing of the national system in real-time is the most significant. Currently, this is done by controlling large scale 'dispatchable' generation to match demand in real-time, which is not straightforward with renewable generation (their output is wholly dependent on the availability of their energy source, e.g. wind or solar irradiation). Alternative solutions, such as managing demand to match the availability of renewable generation, will have to be applied. Note: National Grid is purchasing a greater range of ancillary services to enable this real-time balancing, these include energy storage and Demand Side Response to provide greater flexibility.

The key parties involved in the electricity industry are shown in the 'electricity and natural gas' box on the next page. It is useful to discuss the supply of electricity and natural gas in GB together, as their industry structure is very similar.

LOW CARBON AGENDA SHAPING THE GENERATION MIX

Notable changes to GB's generation mix driven by the low carbon agenda are:

- An increase in both large scale renewables, e.g. hydropower, wind farms and solar arrays, as well as small scale renewable generation, e.g. solar generation and smaller scale wind.
- Renewed interest in nuclear generation as a reliable and low carbon source, following years without new investment. Issues being addressed include disposal of waste and decommissioning of older plants. New plant is very expensive and can take a decade to plan and build.
- Piloting of Carbon Capture and Storage (CCS) to reduce the emissions of fossil fuel generation by capturing and storing their carbon dioxide emissions. This is being investigated as a transition technology.

Further insights into the changing mix of generation may be found at http://fes.nationalgrid.com

GB electricity and gas system – key parties:

Generators (electricity) – Owners and operators of large power stations connected to the transmission network and smaller technologies, often renewable sources, connected to the distribution networks (Distributed Generation).

Gas production and central supply (gas) – Large centralised extraction, processing, and storage of natural gas. This is increasingly supplied from overseas via pipes or ships.

Network operators – Network operators have dedicated geographical areas of operation to avoid duplication of networks. This means that customers do not have a choice of network operators, so networks are a regulated monopoly service.

System operator – National Grid is the electricity and gas system operator in GB, and interacts with generators to ensure that supply and demand is balanced at all times.

Users – Today, most energy users do not interact with the energy system beyond connecting to it, using it and paying for it. This is starting to change, including users who generate their own power from solar panels and export their surplus back into the grid, or connect intelligent energy management systems, and use storage devices. Smart meters will also offer new functionalities likely to engage customers more actively.

Suppliers – Energy suppliers buy energy from the wholesale markets, sell it to customers, and provide metering and billing services. They compete for customers.

Regulator – Ofgem protects the interests of electricity and gas customers; it promotes competition, and regulates and encourages innovation in the network companies.

Aggregators – Aggregation service providers combine the ability of multiple parties to control their energy use and generation (often called Demand Side Response) to sell services to the system, e.g. to help the system operator balance supply and demand.

FURTHER READING…

Helpful information regarding electricity and gas network companies is available from the Energy Networks Association: tinyurl.com/jofse8v

Ofgem provides good information on the structure and operation of UK energy markets:
www.ofgem.gov.uk/publications-and-updates/infographic-energy-network
www.ofgem.gov.uk/publications-and-updates/infographic-bills-prices-and-profits
www.ofgem.gov.uk/network-regulation-riio-model/energy-network-how-it-works-you

Combustible substances

Natural gas

The GB natural gas supply system has many parallels with electricity supply; it is taken from large, centralised supply points and is transported via transmission and distribution networks to users.

It too has developed over time, most notably in changes of source; Town Gas supplies (gas made from coal) were converted to Natural Gas in 1959 and the discovery and exploitation of significant gas reserves in the North Sea has provided high quality and accessible gas supplies for many decades.

The network of pipes that transport gas is operated by Transmission Operators and Gas Distribution Network operators. Whilst electricity supply and demand has to be balanced in real-time, there is more flexibility in the gas supply as there is inherent storage in the form of additional pressure in the gas network, which provides support for the delivery of the peaks of heat demand at the busiest times and the coldest days.

The key uses for natural gas are space and water heating, cooking and industrial processes. It is also a key fuel for the generation of electricity.

Today, GB's native sources of natural gas are not enough to meet our needs and we import the shortfall from abroad. Until recently this was only possible via a network of cross-border gas pipes, making GB dependent, both in price and volume, on the countries to which it was connected.

Two new developments have already started to reduce this dependence: Fracking in GB (see information box) and Liquid Natural Gas (LNG). The latter can be transported globally in tanks and is therefore not dependent on certain pipelines, opening access to the freedom and vulnerabilities of international markets.

THE CONTROVERSY AROUND FRACKING

Fracking, short for hydraulic fracturing, is a new natural gas extraction technique based on fracturing rocks underground by a hydraulically pressurised fluid to create an extensive system of small cracks in deep-rock formations to enable natural gas and other products to flow more freely.

In Great Britain, in common with other countries including the United States (where the industry is most advanced and widespread), this technique has generated significant controversy within government and in local communities. In September 2016, the first shipment of US fracked gas arrived in GB. The UK Government approval to deploy onshore fracking techniques is relatively recent and production is not yet at a commercial scale.

An overview was published by the Royal Academy of Engineering at: www.raeng.org.uk/publications/reports/shale-gas-extraction-in-the-uk

Oil
Like most nations, crude oil has historically been a key energy source for GB. It supplies energy for transport, space and water heating and generation of electricity. The high energy density makes it easy to store significant amounts of energy. Means of extracting, trading and transporting oil are well established, as are the technologies using oil based fuels, e.g. cars and aeroplanes.

The way oil is used has changed significantly over the past decades. Cost and targets for carbon reduction and efficiency resulted in a notable decline in large-scale electricity generation from oil. There is also a focus on optimising the use of what is a valuable resource, e.g. in the production of specialised aviation fuels, feedstocks and plastics, rather than being burned as an energy source.

In today's power system, oil is only used to provide reserve capacity to the grid in case of need and to fuel small-scale (standby) electricity generation to supply loads in case of a cut in power supplies or to provide services to the power system. The begining of a trend towards electricity powered transport of people and goods is also set to reduce oil consumption, but it remains an important fuel for transport today. Use of oil for space and water heating is still common in areas that are not supplied by mains natural gas.

Research and development of like-for-like alternatives to crude oil such as bio-fuels are a key focus area. However, there are challenges such as a limitation to the potential supply volume, cost and difficulties in achieving a comparable energy density and performance. Therefore, oil is likely to remain a part of the energy landscape for the foreseeable future.

Other combustible substances
Other combustible substances used as energy sources in GB include coal and biomass fuels such as wood. These have been in use since long before electricity was established as an energy vector and continue to be used by individuals for cooking, space heating and water heating. Other vectors, such as hydrogen and synthetic fuels, are not widespread but could have the potential to become more so in the future.

Hydrogen is thought to have significant potential as an energy vector in GB as it is clean burning, producing only water. There is a view that the repurposing of the gas networks for use with hydrogen is feasible with some work and could be an attractive option especially for properties in urban and suburban environments. Hydrogen has the advantage that it can be stored in specialised facilities comparable to those used for natural gas, albeit needing about three times the volume (or three times the pressure) due to its lower energy volume density.

Future challenges for mass uptake of hydrogen include the need to develop large-scale, low-cost production facilities. Production using electrolysis would require very large supplies of decarbonised electricity, which even if attainable, could itself have a potentially greater system value than the gas produced. Hydrogen can also be produced from natural gas using a methane reforming process, though this route actually increases primary energy consumption.

There is also potential for using other bio or green gases within the existing natural gas network and projects to explore blending these with conventional gas sources are appearing on the horizon.

HYDROGEN AS AN ENERGY STORE

One approach that has been proposed is to use excess renewable generation, at times when the load on the network is lower than the electricity generated, to generate hydrogen. This hydrogen can then be stored for conversion back into electricity later, or injected into the national gas network. At present, the use of hydrogen in this way is likely to be in small quantities, but this could change if it became commercially and technically viable. This would assist in enabling renewable sources to be used to their full potential.

Heat carrying substances

The delivery of energy for space and water heating using heat networks (carrying a hot fluid, like water or steam) has been in use in GB for decades. The early networks from the 1960s have tainted the reputation of heat networks with poor efficiency and performance, but technology has come far. It can generally provide heat at a lower cost and environmental impact compared with individual fossil fuel boilers in each building, as it can utilise waste heat or a more energy efficient centralised heat source, potentially combined with generation of another vector such as electricity (Combined Heat and Power, CHP).

Heat networks continue to be built and the pace is increasing. The combination of low carbon targets, together with incentives and increase of distributed generation has seen new, innovative heat schemes being developed.

An example of a modern, multi-purpose solution is a CHP plant combined with heat storage. This facility enables the operator to offer flexible, responsive demand services to the electricity system while being able to supply heat to the network reliably with the support of heat storage tanks.

Further challenges for the expansion of heat networks include the lack of a widespread market structure, operational approach, industry standard or regulatory oversight.

Drivers for Change

Meeting the new energy challenge

The energy challenge of several decades ago, before GB energy industry privatisation, was relatively straightforward: to deliver energy to customers reliably, economically and on demand. Over time this challenge has become more complex as the requirements, stakeholders and dynamics of the sector have started to change.

About fifteen years ago the term: *Energy Trilemma - the need to protect the environment, while maintaining an energy supply that is affordable and reliable,* was coined to capture the post-privatisation energy challenge.

This captures the trade-offs that must be made between these three requirements; energy sources that are low carbon (e.g. nuclear power, solar power) are not always the least costly, energy efficient, or most secure sources. Similarly, low cost energy (e.g. coal and natural gas) may not be low carbon or secure in the long-term.

The trilemma challenge remains very much valid today and its scope is becoming broader and increasingly complex. Energy is used by every member of society and is essential to the production of products we buy and use, the buildings and infrastructure that surrounds us, and the services on which we rely. This dependence is not only set to increase, but the nature of energy use, the form it is delivered in, and the structure or 'architecture' of the energy system are all in the process of transformation.

Taking into account further privatisation and commercialisation, changes to our social structure and a strong sense of environmental awareness, today's new energy challenge can be summarised as:

> **The energy challenge** is to deliver the required utility to individuals and society, such as a comfortable living, transport and choice between and convenience of services, in a way that balances reliability, cost, environmental impact and long term economic, commercial, technical and societal acceptance.

To meet the challenge we need to balance these individual decision factors until a satisfactory outcome is achieved - every day, every minute and every second. Adding to the complexity of solving this challenge are the following considerations:

- The importance (weighting) of each decision factor is not a given, but is dependent on social, environment or economic circumstances.
- The emergence of less tangible or less 'rational' drivers emerging such as a greater sense of community and identity, a desire to source energy locally, and new ways to offer 'value' (taking into account the benefit to the individual and to GB society as a whole) rather than simply the 'lowest price'.

Key drivers for change

The drivers for change include the implication of technical, economical, societal, environmental and political developments on meeting the energy challenge. These drivers include changes that are already happening, creating visible impact and opportunities which are available to be leveraged, such as new technologies and approaches which are being developed.

- **Changing customer behaviour: generation, energy management and service expectations –** The way energy is used and the interaction that users have with the rest of the system, is constantly evolving. Customers are no longer simply passive users, but are starting to have direct interaction, by generating electricity or managing their usage. Customers' expectations of service are also changing, increasingly driven by their positive experiences in other industries, e.g. one-hour delivery slots, managing their accounts online and the ability to easily buy and sell using peer-to-peer online services.

- **Energy communities –** Energy communities include groups that join together with a common goal, for example decarbonisation, localism or taking control of energy and service provision from traditional utilities. For example, they may jointly invest in renewable power generation, or use the same energy management or aggregation service. Examples of energy communities include Geographical and Virtual energy communities. Geographical energy communities may even aim to develop a local holistic energy service, providing needs like heating, power, and transport, and enabling peer-to-peer trading of energy and services optimised to meet their goals. 'Virtual communities' are those that are linked by an interest or product e.g. procurement club or the same make of electric vehicle.

- **Increased use of intermittent energy sources –** It is generally not possible to control the output of renewable power generation such as wind or solar. As these generation sources become more prevalent, driven by the need for a sustainable energy supply, it becomes increasingly difficult to balance demand and supply in real-time. This is driving a need for new ways of doing things, for example leveraging energy users' ability to manage their energy use (Demand Side Flexibility), which is a flexibility service that they sell to the system.

- **Advances in energy system technology and innovation –** There are technological developments and innovation within the energy sector all the time, for example, renewable electricity generation technologies are becoming cheaper and more reliable as they develop, and if local storage becomes a viable complimentary technology, then this could be a further game changer.

- **Advances in consumer technology and service –** Development of energy related consumer technology is significant and fast moving: e.g. energy management systems, electric vehicles, building scale generation and even smartphones and connected devices which enable interactive and holistic services. These developments can provide easy ways for people to interact with the energy system. Some of these technologies are already having a disruptive impact on the energy system today and present a real opportunity for society and the energy system.

- **Advances in computing technology and connectivity –** The advances in computing technology and connectivity over the years is enabling the power system to become more decentralised and interactive. This has increased the level of complexity by the increased use of sensors, data and communication across the whole-system, enabling active system management and active interaction with people and organisations which use energy through smart meters, time of use tariffs, aggregators and energy management.

- **Vulnerability to cyber-attacks –** The increased use of IT and communication brings great advantages, but also increases the system's vulnerability to cyber-attacks, which is a prominent and rising concern in many sectors. In the extreme, such attacks may shut down service provision, or give access to data about individuals including detailed energy use which can be used to understand patterns of home activities. Therefore, this risk is taken very seriously within the sector.

- **Advances in other sectors –** Innovation in other sectors, such as in factory automation or the automotive sector, can influence or create opportunity in the energy sector. For example, the development of electric vehicle battery systems can also advance the capability for battery electricity storage for other applications. Bringing innovation from other sectors, such as automation or health, is referred to as 'horizontal innovation'.

Mapping the Complexity Using the Smart Energy Picture

The use of visualisation techniques often helps us to understand and analyse complex landscapes such as the energy system. Various methods are available, such as scenario planning and/or system modelling, each with their advantages and weaknesses.

In order to explore the energy system, focusing on the areas of change, challenge and opportunity across the landscapes, we have developed the Smart Energy Picture (SEP) – an adapted version of the Layer Model approach.

A Layer Model represents aspects of a complex system as layers, populated by views of the system from a specific aspect and with interactions between them.

The SEP is illustrated below. Each of the layers are explained and defined. An important aspect of this picture is the **interaction between the layers**, which can be described by allowing concepts to span multiple layers.

In the following sections we use the SEP to explore six distinct themes, with trends and developments which together add up to game-changing influences affecting the energy system as a whole, and could have significant impact, risk and potential benefit for stakeholders. We present these themes together with our insights in order to inform you and help you **realise the benefits of these trends and changes.**

FURTHER READING. SCENARIO EXAMPLES

National Grid – Future Energy Scenarios: fes.nationalgrid.com/
The Climate Change Committee: tinyurl.com/hzxeh54

UKERC – Scenarios for the Development of Smart Grids in the UK: tinyurl.com/gqwp9gf

ETI – UK Scenarios for Low Carbon Energy System Transition: tinyurl.com/j3rxh27

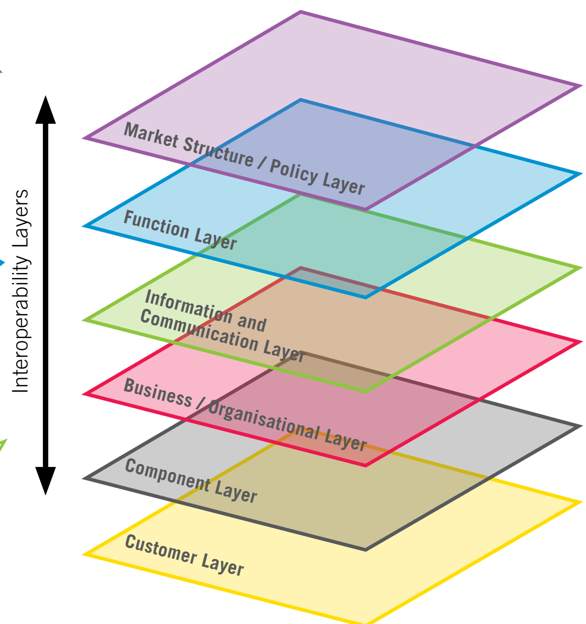
THE SMART GRID ARCHITECTURE MODEL (SGAM)

The diagram used in this briefing is based on the SGAM; a Layer Model developed by European standards bodies as a framework to understand Smart Grid Architecture and the gaps that needed to be closed. The model was developed particularly for the electricity industry, and from a European point of view. We have adapted it to make it suitable for the GB whole energy system.

The Market Structure Layer describes the structure and landscape that the layers below fit into, and includes government policy, legislation, regulation, standards, etc.

The Function Layer represents the functions needed to deliver the business model and drives the specifications that in turn are implemented in the layers below.

The Information and Communication Layer represents the data structures and overlaid communication infrastructure that is needed to control, monitor and execute the required commands on the physical infrastructure below.



The Business/Organisational Layer represents the commercial activity and the business model that are being implemented and link to the layers below.

The Component Layer represents the physical infrastructure, including the energy conversion, transportation, storage and demand assets. It also includes the monitoring and control equipment, the operational equipment and control room, the infrastructure needed for billing and trading.

The Customer Layer represents the users of the system including domestic, commercial, industrial, communities and their loads, and (distributed) generation.

Theme 1: Understand Your Customer: Comfort, Choice and Acceptance

The customer is now considered to be the key focus of the energy transition. More open to voice their opinion than ever before; they want value for money, and the appropriate level of service. Increasingly, customers are interested in the sustainability of energy services, or localisation of services and benefits. If their wants and needs are not met, they seek choices about how their wants and needs can best be fulfilled. As their requirements evolve, so must the system, regulation and business models. Listed below are some general trends in consumer interactions that are driving change. For some it is early days, but they could have a transformational impact as they mature and as aggregated participation increases.

Messages to take away

Increased user engagement presents opportunities to leverage Demand Side Flexibility services to support the balance between demand and intermittent renewable generation. There are opportunities for new parties and new business models to offer a greater range of services to customers. This includes an increase in prevalence of energy communities offering a local energy focus. These developments represent new possibilities for customers and service providers. However, it is key that those who choose not to participate, or are unable to, are not overlooked.

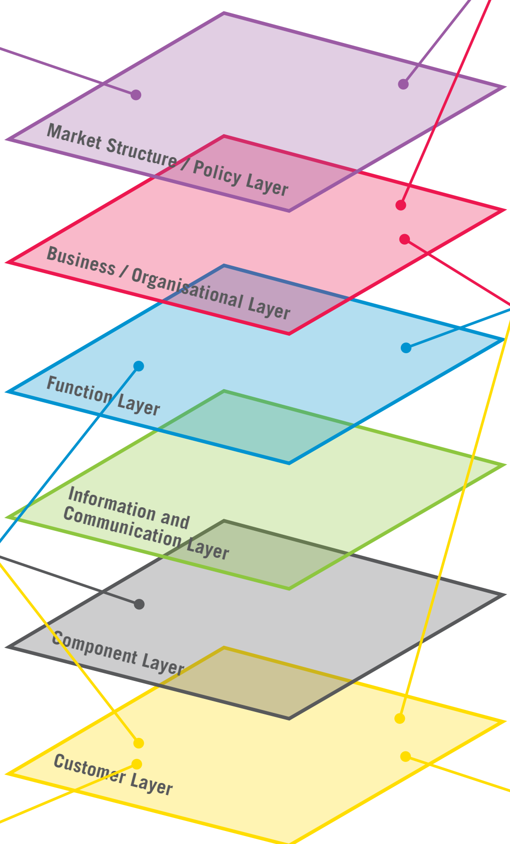
Key trends, opportunities and barriers are explored further in the Smart Energy Picture below:

In response to changing customer expectations, values and technology uptake, **new players and new business models enter the market to offer new services,** e.g. Aggregators who manage a portfolio of active consumers and energy community bodies. This can then enable customers to choose from a wider range of service choices, including the possibility to opt for services tailored to them.

Engaged customers and the uptake of controllable demand technologies (electric vehicles, heat pumps) presents an **opportunity to harness Demand Side Response services** to help support the energy system.

The uptake of technologies such as distributed generation, electric vehicles, and energy management systems is changing the shape of demand. **The energy system and its operation will need to adapt** to this change, and there are **growing opportunities to offer new services** to customers and stakeholders.

There is an increase in direct engagement of users in the electricity system, through generating electricity and changing demand behaviour. This includes individual users, particularly large industrial users, or groups of smaller users and services which are collected together and represented by an Aggregator.



Energy efficiency technologies can be cost-effective, e.g insulation and LED lights. Not using energy is cheaper than generating low carbon energy.

Increased user empowerment
There is a trend in energy customers taking control of their energy use, with the support of energy information and management and small generation technologies. This changes the relationships the users have with the energy system and its players, either as individuals or communities.

The expectations that customers have in their service provision is changing as other industries develop customer service approaches such as 24-hour service, ability to buy and sell peer-to-peer easily using online services, online accounts, data availability and control, and customisation, it is likely that people will expect the same offerings from the energy system.

The majority of individuals are unlikely to want to become 'energy managers', but **technology, including automation, can make it easy for people to interact with the energy system** making this accessible to many more people.
Development of consumer energy management and automation technology is **inhibited by the lack of cohesive standards,** initial costs and level of understanding.

Theme 2: Design for Flexibility

The requirements of the energy industry are evolving and changing at an increasing pace. This is driven by the increasing focus on sustainability and best value, the changing energy expectations and behaviour of users and opportunities bought by new technology. We cannot foresee with certainty how these trends will develop or what the system needs to do to cater for this. In order for the energy system to remain fit for purpose, it will need to adapt and change with these requirements, without compromising resilience and security of supply.

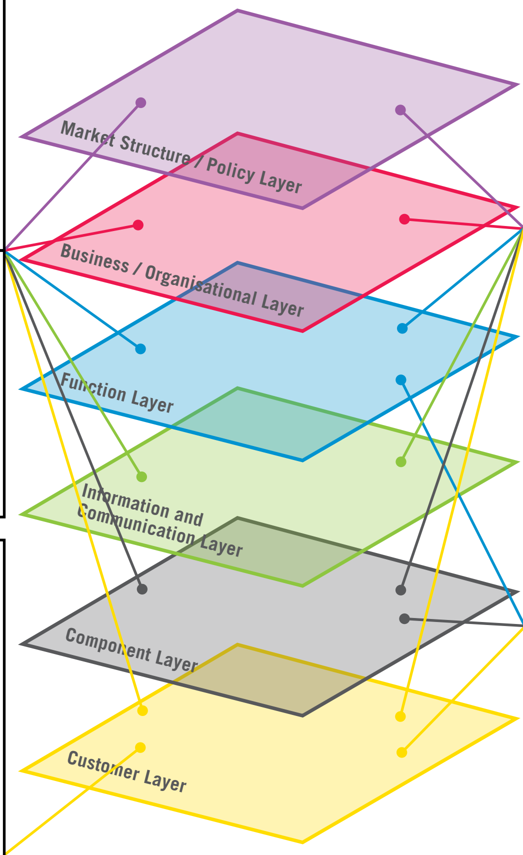
Messages to take away

Going forward it is clear that flexibility will be key. The ability to offer flexibility in energy use, generation and storage has a financial value and this enables engaged customers to offer a beneficial service and share in the benefits. This creates plenty of new opportunities for business models (e.g. using price signals) and commercial enterprises. Disrupting technologies often bring the need for flexibility but should nevertheless be embraced as they are also the providers of flexibility.

The need for flexibility, agility and adaptability is equally pertinent for the infrastructure and its operation and the regulatory and commercial structures around it. There are already efforts being made in this area: Ofgem is reviewing their regulatory framework to account for flexibility, large businesses are reviewing their internal structures, and many new enterprises are starting up.

Changes in requirements, landscape, and opportunities will develop at different rates – for example the changes associated with the uptake of technology beyond the meter can be very fast, while major infrastructure may only change slowly. A balance must be made between maintaining stability and resilience, with the flexibility to change with these trends.

User adoption of new energy technologies is increasing, and this can develop quickly. For example, electric vehicles, heat pumps, energy storage, distributed generation, and home and building energy management and automation. This is starting to have an impact on the energy use patterns of the country as a whole, and making use more dynamic and less predictable. Continual development of portable smart technology and connected devices also potentially enable connected holistic services.



As well as harnessing new opportunities and meeting new requirements, **the energy sector will have to adapt to new and evolving threats.** These include malicious attacks, including cyber-attack, as well as developing resilience to a range of scenarios such as fluctuating energy sources and the activities of all system participants and actors in the system, including a potentially large number of new participants with independent goals and capabilities.

Examples of technologies that will have major impact on the system include:
New and non-traditional service offerings, such as the introduction of peer-to-peer trading, energy communities and Demand Side Response.
The increase in distributed electricity generation from renewable and intermittent sources.
The possibility of natural gas 'fracking', new nuclear electricity generation, and 'clean' fossil fuel electricity using carbon capture and storage (CCS).
The increase in 'smart infrastructure', such as Smart Meters, Smart Cities and the Internet of Things (IoT).

Theme 3: Use New Approaches to Drive Sustainability and Efficiency

There is a significant focus on reducing carbon emissions, protecting the environment and improving air quality, coming both from government policy drivers and from societal pressures where the public has embraced sustainability and is driving towards greater use of clean technologies. The energy system is both a key contributor to the carbon emissions generated and a key enabler for reducing them.

However, balanced with the requirement for a reliable and resilient energy supply. It is also vitally important to consider the cost of the energy to the end users, as energy has become a core need within society and fuel poverty must be addressed.

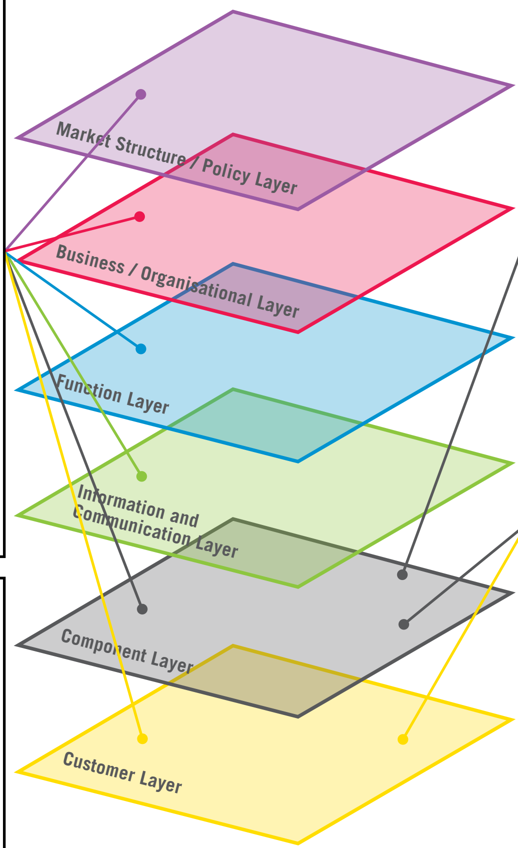
Messages to take away

There are a range of new approaches and technologies that can be used to drive a sustainable, decarbonised energy system, e.g increased adoption of renewable energy sources, Demand Side Response, energy storage, and multi-vector optimisation. Implementing these technologies requires a substantial change to today's energy landscape, which would be a significant challenge.

Challenges in reducing the environmental impact of the energy system are included below:

There are a number of key barriers in today's energy system landscape which are inhibiting energy sustainability and efficiency.
Energy storage could play a key role in enabling integration of intermittent renewable energy sources. However, there is **limited incentive for investment in energy storage.**
There is only limited incentive for energy efficiency within electricity networks, meaning that useful energy is being wasted.
High capital costs of energy efficiency and low carbon technologies is acting as a barrier to those individuals and organisations who otherwise want to improve their sustainability.
Changing government incentives and volatile commodity prices make investment in new generation technologies, such as renewables, problematic.

Energy communities are an opportunity for groups of people to make energy decisions in a joined-up way.
They may, for example, jointly invest in renewable power generation equipment. Virtual communities may not be aware that they are part of a community, but still participate in joint behaviour, for example those who use the same energy management or aggregation service. Geographical energy communities may even aim to develop a local holistic energy service, providing needs optimised to meet their goals.



A low carbon energy system will most likely include a mix of vectors. Being able to interchange between vectors would enable optimisation according to availability, carbon intensity and cost ensuring that all requirements are balanced. This is called a Multi Energy Vector system.

Renewable generation is key to reducing carbon intensity of energy supply. They can have large capital costs, but will reduce as the technologies mature. Some renewables are now competitive with conventional supply. Due to their intermittent nature, they **require significant back up generation, storage or demand flexibility** to be adopted at scale.

Engaged customers, and the uptake of controllable demand technologies (electric vehicles, heat pumps) presents an **opportunity to harness Demand Side Response which can help support an energy system with significant levels of sustainable but intermittent energy sources,** which may otherwise struggle to match generation and demand in real time.

Energy efficiency and sustainability are generally seen as important to users, but few are willing to pay additional costs. To gain public acceptance, **a future low carbon energy supply should, as far as possible, be as convenient, reliable and deliver best value** from the point of view of the customer and society. While this is a challenge, much could be achieved through innovation and strategic development.

Theme 4: Collaborate Cross-Sector for Optimised Service Delivery

The operation and management of each of the energy vectors in use in GB today have little interaction with each other. Even within the vectors there is limited collaboration across organisational and market boundaries. However, there is a growing view that there are potential benefits that can be gained through enabling and exploiting interactions between energy vectors and process stages and even between the energy sector and other sectors, e.g. to share learning and innovation.

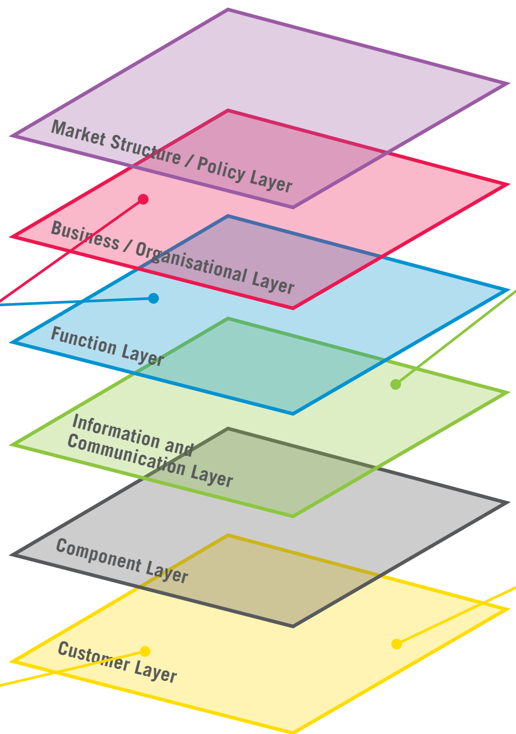
This concept is explored further in the Smart Energy Picture below:

Messages to take away

The 'whole energy system' approach, across vectors and process stages, and between the energy sector and other sectors, can present significant opportunity for new technologies, methods, and services that are bundled across vectors and sectors, tailored for the needs of the individual and society. Making this approach a reality in a widespread way is a significant step forward from today's system, but there are already activities at a smaller scale which are beginning to exploit these opportunities, such as heat and power interplay at a local level.

Generally, **each energy vector and the functions within the vectors, are managed separately** with few interactions across functional or organisational barriers. For example, there is little collaboration between suppliers and network operators. This separation of activities has largely been encouraged to promote free-market behaviours. There is some interaction on a technical level; e.g. some electricity generation uses gas, some equipment in the gas network relies on electricity to operate.
A 'whole-system approach' to the energy sector, including across energy vectors and process stages, **could bring benefits in efficiency, flexibility, and resilience.** For example, interaction between vectors in the supply and demand could be optimised for efficiency, decarbonisation, cost and resilience to fluctuating supplies.

A multi vector and whole-system approach could enable the offering of new or bundled services which are tailored to the needs of the customer and the availability of energy sources.



Interaction with other sectors could bring additional benefits. Managing the link to IT and communications sectors could support taking advantage of advances in these areas. Sharing innovation across sectors is also an opportunity to bring additional benefit.

Data sharing across functional and organisational boundaries could support more informed forecasting, modelling and provision of services. This is a particular challenge today, but must be overcome to enable future benefits.

Most homes and buildings are already 'multi vector'; fuelled with a mix of electricity and natural gas. **There is an opportunity to improve the flexibility and resilience of our buildings to fluctuating supplies and process by being able to arbitrage between these sources more freely.** For example, hybrid heat pumps can provide space and water heating through a mix of electricity and gas. This balance could, in the future, be controlled to optimise carbon efficiency, cost, and resilience.

COMMENT

Is it true to say we have an energy ***system*** in GB? A system can be defined as **organised**, with **interrelated elements** that work together towards a **goal**. Within the GB power system, some of the functions are interrelated, but they are not organised as a whole. In fact, GB energy supply can be seen as many separate systems, not a single system. The need for a 'whole-systems' approach to electricity is now emerging strongly, for example see the IET/Energy Systems Catapult Future Power System Architecture project (FPSA).

Theme 5: Co-ordinate and Collaborate in Innovation

Innovation is vital to continually improving the energy system and addressing new and developing challenges. This includes early stage research, through to deployment, and must cover technical, commercial, regulatory and business frameworks. Opportunities may be leveraged through innovation and solutions developed in other sectors, e.g. market service disruptions like AirBnB, Uber, and Amazon, or technical developments such as storage in the transport sector, etc., through horizontal innovation. The barriers and opportunities of innovation in the energy system are summarised below:

Messages to take away

There is active innovation throughout the sector. However, there would be advantages in significantly greater collaboration across the energy system, perhaps focused on a co-ordinated approach and shared vision. Innovation can be at all scales – from local to national.

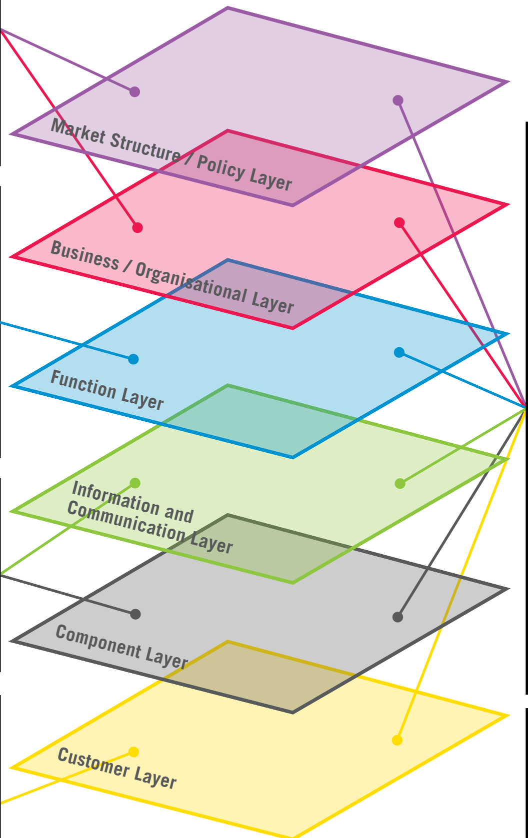
The key barriers to innovation are the need to manage risk, the legacy infrastructure and culture within organisations and regulation. The focus on late stage development limits the future pipeline of innovation and new ideas that can come into the system. A shortage of skills is already impacting the industry and this is set to be a major barrier to bringing about new innovation.

Existing electricity and gas innovation is generally focused on demonstration of concepts which are nearer to commercial readiness, which involves lower commercial and technical risk, as opposed to early R&D.
New players such as energy communities are more likely to explore more innovative options.

It is likely that cross-sector and multi-discipline skills will be vital to develop, demonstrate and implement new technologies and approaches. This is within a back-drop of a sector with an existing skills gap. **Developing skills and applying them in new ways could bring significant opportunity and benefit the energy system.**

There is opportunity to develop the established legacy equipment and procedures in the system, in particular to enable improved monitoring, automation and information and communication infrastructure throughout the system.

Innovation in demand side technology can be fast, and take-up can be explosive. This presents one of the best opportunities for change and development for the energy system. In order for this opportunity to be leveraged, inter-operability and co-ordination must be considered.



There are significant innovation activities across the sector.
Within the private sector, innovation is driven by the organisations and market competition. Electricity and gas network innovation is encouraged by the regulator, Ofgem.
Public sector funding for innovation is managed through The Research Council's Energy Programme (RCEP) and Innovate UK, and supported by HubNet and UKERC funding, and through mechanisms such as the Energy Catalyst funding and the Energy Systems Catapult.
In parallel, the developments in demand side technologies and energy use are moving quickly. These are often driven by parties traditionally outside of the energy system, developing products that appeal to users, and which could be widely adopted very quickly.

Co-ordinating innovation and development activities across the whole energy system would enable it to be optimised to meet developing challenges. This should include innovation from early Research and Development, through demonstration, and implementation on the system.

Theme 6: Unlock and protect the power of data

Data is essential to operate a smart, flexible energy system. This need ranges from technical data to manage the system in a flexible way, to customer data to develop tailored commercial services. Today's energy system is not consistently monitored. For instance, large centralised energy assets and energy users have detailed monitoring, while smaller assets are less well monitored, and visibility of energy use is sparse. Yet it is the smaller assets that perhaps hold the greatest changes, challenges and opportunities will unfold. Some key considerations and challenges in data and IT requirements are included below:

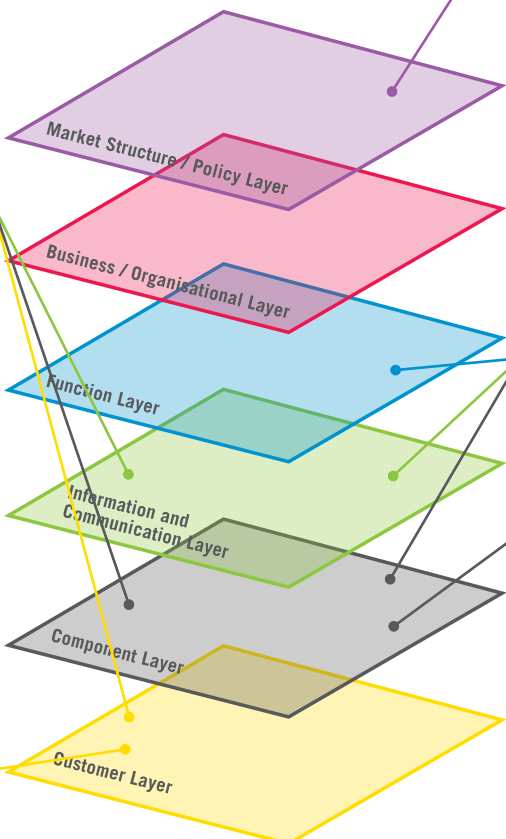
Messages to take away

Increased observability of the energy system assets with greater automation across the whole-system will be a key step towards integrating innovative system technologies and operation. There is a need to understand what data is needed and how it should be handled to maximum benefit and how it can be made available. As future requirements develop over time, IT systems must be flexible and able to meet rapidly changing requirements. New business models are likely to require new governance, commercial arrangements, technologies, etc., to enable innovation such as blockchain.

The data collection and visibility in the energy system infrastructure is limited.
Large centralised energy assets, such as gas supply, electricity generation, and energy transmission systems, have detailed monitoring integrated.
Smaller assets, such as those in electricity and gas distribution networks, are less well monitored.
Visibility of energy use is sparse with domestic meters being read biannually. Larger businesses have half-hourly metering, giving a picture of energy consumption profiles and some may have more detailed monitoring within their premises.

Sharing data across the whole would enable collaboration and optimisation. However, **sharing data across organisational and functional boundaries is problematic in today's energy system landscape.**

There is **increased data collection at a customer level,** with the adoption of energy monitoring and management technology, and the roll out of smart meters – this can be used by customers to make informed energy choices, and by the system to improve management and modelling. However, this is personal data and needs to be treated carefully.



There has been a recent focus on increasing collection and use of data but there is a need to consider how to make best use of the data and have the right information to see the big picture.

ICT has to be agile to cope with changing technology, protocols and demands.

There is an **extensive legacy ICT infrastructure** that needs to be upgraded within a strategic plan. The lifetime of power assets may be several decades, whereas ICT lifetime is significantly shorter.

Future energy system technologies are likely to require a **huge increase in data from distributed sources** that will need incorporating with existing systems.

The safety and security of energy assets is critical to maintain supply and prevent risk of dangerous incidents. In particular, **cyber security is increasing in importance** as assets become more connected and autonomous.

Generally, network operation systems are isolated from the outside world, but future developments in energy system technology may result in the operation systems to be connected for live information exchange with other systems. **Concerns about system security may prevent the adoption of new approaches** that would otherwise bring benefits.

Achieving Change and Realising the Benefit

This paper has discussed the complexity of today's energy system landscape and the significant levels of change happening now and in the future, bringing both disruption and opportunity to the sector.

We think that it is important to develop a clear vision as to how emerging trends and activities fit together and how the system will meet society's energy requirements. This vision would have to include the following key themes:

- **Understand your customer – comfort, choice and acceptance –** In order for the energy system to remain fit for purpose, the needs and wants of customers and society must be central. These needs are changing, presenting the need and opportunity for new services, business models, and parties to enter the market. Customer acceptance of any change that is implemented is vital and should not be underestimated.

- **Design for flexibility –** The energy system must be agile and flexible to adapt to external change, threats and opportunities as they happen. Resilience within this flexibility will enable safe and reliable supplies to be maintained. 'Optionality' for the future energy system includes, for example, designing-in flexibility to enable investment and activities that embrace future technology or service opportunities. This avoids restricting the evolution of the system to a narrow pathway, which is a particular risk for utility systems where the life of equipment is long.

- **Use new approaches to drive sustainability and efficiency –** New approaches, such as Demand Side Response, community energy initiatives, and cross-sector collaboration can contribute towards a sustainable energy system. To ensure public acceptance, a future sustainable energy supply should be as convenient, reliable, and best value by today's standards, and people who can not, or choose not to, participate in new ways of doing things should not be disadvantaged.

- **Collaborate across the sector for optimised service delivery –** Increasing collaboration across the energy sector is likely to bring significant advantage in optimisation for best value, improved sustainability and resilience, as well as opportunity for new, bundled services. However, there is currently no shared vision for the energy system as a whole and there are significant barriers to exchange data and information across organisational and functional boundaries.

- **Co-ordinate and collaborate in innovation –** Aligning innovation across the whole energy system and with other sectors, will mean that activity is efficient and focused. Significant effort is needed in innovation from early Research and Development through to deployment, and innovation should include technical, commercial, regulatory and business frameworks. There is a significant skills requirement to innovate and implement changes, which must be addressed. Innovation is only any use if the best results become business as usual, this is a major challenge today and usually relates not to technical issues but the commercial or market structure challenges.

- **Unlock the power of data –** Increased visibility of the energy system is key for integrated and interactive energy management, and presents opportunity for new services tailored to the needs and activities of the customer. Interoperability is an essential design requirement. This ensures that all the parts work together in an integrated whole-system approach, enabling data exchange and a seamless consumer experience. Sharing data across the sector is important to unlock its value, but security and resilience to cyber threats is vital.

To achieve this vision, significant change must take place. Action is needed soon in order to maximise benefit and avoid risk of being able to meet the energy needs of society. This action can build on the significant activities already underway, including governmental targets and policies, technology and commercial innovation and increased interaction across the sector, including emerging and new participants.

Watch this Space

This overview briefing is the first in a series exploring the key changes in the energy sector as a whole, the steps enabling change in a positive direction and provide pointers to benefit from change.

Future briefings will provide a more in-depth look at some of the 'big questions' that are common across all themes.

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The IET - Working to Engineer a Better World

Sharing information is key to achieve positive change

It is the IET's vision to engineer a better world by inspiring, informing and influencing the global engineering community and supporting technology innovation to meet the needs of society. The IET Energy Sector Executive Committee comprises volunteer industry professionals whose knowledge and experience span the energy sector.

In these times of change, we aim to disseminate information and concepts about the sector in order to support its development and help bring forward innovative products, services and solutions that will benefit customers, the industry and wider society.

Helping non-specialists navigate the energy sector

This series is aimed at those who are not specialists in this sector but do engage with it, such as decision-makers in small to medium enterprises, investors, local authorities and community energy groups.

It is meant to be readable, and to cover the relevant key points in a simple and straightforward manner. It is not intended to be exhaustive in its approach.

As well as facts and descriptive material, we have included comment and opinions that we hope are informative and interesting, and will promote debate. We have attempted to make clear which parts are opinion and which are factual statements.

We welcome your feedback

Your feedback is encouraged and appreciated. We develop these briefings for you and we welcome your comments. For further information, to ask questions or to participate in the debate:

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