NATIONAL ENGINEERING POLICY CENTRE

ROYAL ACADEMY OF ENGINEERING

Net Zero: A systems perspective on the climate challenge

Achieving a thriving, low-carbon economy through rapid and large-scale systemic change

Introduction

The scale of the net zero challenge

In May 2019 the Committee on Climate Change (CCC) published its report outlining the technical feasibility of **reaching net zero greenhouse gas emissions by 2050**.[1] On 27 June the UK government enshrined this target into law.

The scale and impact of the COVID-19 global pandemic has, for now, shifted the UK government's immediate focus away from climate change. During this time of national emergency, it is vital that we do not lose sight of the critical present-day global threat posed by climate change. There will be important lessons to be learned from our shared experience of COVID-19 that can be usefully applied to the massive climate challenge that still lies ahead. For example, there will be lessons around future resilience planning and rebuilding the economy. We will also need to consider how we can unite behind a common purpose and take positive action to create rapid behavioural, cultural and economic change.

The UK has less than 1,600 weeks to meet the target of net zero territorial emissions; it is a massive undertaking. It will involve **simultaneous transformation of several vital, interconnected infrastructure systems**: from transport and housing, to energy and manufacturing. It requires developing whole new industries to maturity and supporting sweeping societal, cultural, behavioural and structural change. A strong government-led vision for 2050 is needed now to drive coordinated, achievable action across all parts of society and government, with urgency and ambition.

The net zero target is ambitious, and the nation is currently not on track to meet this 2050 target.[2] **A step change in policies, practices and behaviours is required to address the challenge of net zero territorial emissions**. 'Net zero' means that every sector, even those that are difficult to decarbonise, must now plan for rapid decarbonisation.[3]

1 Committee on Climate Change, *Net Zero Technical Report*. (2019) [Accessed March 2020]..

2 Committee on Climate Change, *Reducing UK emissions - 2019 Progress Report to Parliament*. (2019) [Accessed March 2020].

3 It is important to note that reaching net zero is not only about CO2 emissions but all greenhouse gases, including methane and F-Gases. However, decarbonisation will be used as a shorthand for emissions reduction throughout this paper.

Systems thinking – The role of engineering

Rapidly reducing bulk territorial emissions requires integration and deployment of viable known technologies at scale and pace; a challenge that the engineering community can play a vital role in and is uniquely placed and enthusiastic to support. It is engineers from every discipline that will design, build, retrofit, operate and make safe the infrastructure and technologies for a decarbonised UK to be fully achieved.

Decarbonisation is a unique policy goal, because of the scale of ambition, perceived long timescales, the breadth of policy areas which it links to, and the number of stakeholders which must work towards a shared and yet uncertain goal. Acknowledging the complexity and uncertainty offers entirely new ways of tackling the challenge.

Several policy areas and economic sectors are best viewed as interconnected systems (listed below); the **scale of cumulative, connected change** across these areas requires complete systemic transformation.

Government faces the challenge of designing and implementing policy across all economic sectors. This is an immense task, but an achievable one given the right approach. As engineers involved in designing systems, we can also **apply systems thinking to complex challenges such as decarbonisation**. Our experience in bringing together technological, financial, regulatory, legal, ethics, workforce and public-facing elements in practical solutions can be brought to bear on policymaking and decarbonisation.

This paper introduces the National Engineering Policy Centre's (NEPC) project on decarbonisation, which will explore systems implications of the transition to net zero and offer advice to government and other stakeholders to support urgent and difficult decisions. The project will be **underpinned by engineering realities** that inform technological and commercial feasibility, cost, integrity, safety, security and resilience, and timescales for deployment. It builds on earlier work by the Royal Academy of Engineering,[4] professional engineering institutions and others, including the Prime Minister's Council for Science and Technology (CST),[5] which set out the importance of a whole-system approach and explored the role of low-carbon technologies. **Please see the case study in annex A**.

The NEPC has convened a diverse working group of experts to oversee and peer review this work, and to function as a forum for debate. Experts will source ideas and gather evidence to feed into the project. The group will maintain a **strong quorum of engineering expertise and will bring in knowledge and evidence beyond engineering**, sourced from academia, industry and government. This project will be driven by engineering and, in adopting a systems approach, the group will draw heavily on **insights and perspectives from other disciplines such as social and system sciences**.

4 *A Critical Time for Energy Policy*, Royal Academy of Engineering, Oct 2015, https://www.raeng.org.uk/publications/reports/a-critical-time-for-uk-energy-policy

5 Council for Science and Technology, A Systems Approach to Delivering Net Zero: *Recommendations from the Prime Minister's Council for Science and Technology*. (2020) [UNPUBLISHED]

Project vision

The NEPC vision for this project is of a thriving, low-carbon economy by 2050, resulting from rapid and coordinated action at scale, across sectors, led by government and with a strong public mandate.

Over the next 18 months, the working group will focus its efforts on identifying and exploring priorities for action to lay the foundations for a net zero UK. It will consult widely and publish evidence-based advice and commentary on a range of topics, especially those that cut across different sectors. A full list of topics that the working group is interested in covering in this project can be found at the end of this paper (*see page 7*).

The future of the UK's decarbonisation and path to net zero is contingent on **key decisions made by the government during this parliament**. The NEPC wants to inform and support this critical decision-making with regular evidence-based briefings and papers. We will identify actions that can be taken now across different sectors and technologies, as part of the system transition to net zero.

NATIONAL ENGINEERING POLICY CENTRE

Connecting policymakers with engineering

- **We are a unified voice** for 39 professional engineering organisations, representing 450,000 engineers, 19% of the UK workforce, and over a quarter of registered UK companies. It is a partnership led by the Royal Academy of Engineering.
- We give policymakers a single route to advice from across the engineering profession.
- We inform and respond to policy issues of national importance, for the benefit of society.

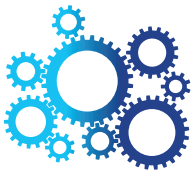
Our role as the UK's National Engineering Policy Centre is to inform, shape and stimulate the bold and difficult, but potentially high-reward, decarbonisation action that is urgently required.

UK decarbonisation: opportunities and challenges

The UK has set itself on a path to reaching net zero territorial emissions by 2050. This is a transformational goal that is even more challenging when coupled with the need to reduce emissions embedded in UK imports.

OPPORTUNITIES

Finding new ways to live within the resource constraints of the planet, **addressing societal challenges, securing long-lasting and positive change to create a world-leading decarbonised industrial economy**. By pioneering this global transition, the UK can secure export opportunities, build its future skills capability and safeguard resilience of critical national infrastructure.



Systemic transformation of the UK will require cumulative change across transport, manufacturing, agriculture, and the built environment. Three decades is a very short time to completely renew, upgrade, install and secure entire parts of the UK's national infrastructure but tough decisions made by government during this parliament will open up new decarbonisation opportunities for the future.

Rapid technology development and disruption will occur in the next 30 years and solutions will need to be mass produced and adopted by 2040, to significantly contribute to reaching net zero; for example, heavy goods vehicle (HGV) replacements and carbon capture and storage (CCS).

Using creativity and systems thinking to minimise the risk of failure and to ensure societal and economic benefits are fully realised in a low carbon future, for example, ensuring quality of life, guaranteeing job security and creating a skilled workforce.

CHALLENGES

The UK must play a **strong international leadership role** to create a sustainable and inclusive global economy, or it will risk leaving future generations impoverished and the nation less commercially competitive.

Replacing or retrofitting all major emissions sources – from heating systems to coal, oil and gas power generation, and from all modes of transport to energy-intensive industry – is a deployment challenge of unprecedented scale and pace.

Individual infrastructure projects are usually planned, developed and built over decades.[6] **This concurrent and cross-sectoral engineering challenge must not be underestimated**.

Decarbonisation in the UK relies heavily on sweeping demand reduction measures, substantial behavioural and societal changes and the development of entire new industries for negative emissions technologies and hydrogen.[7]

Deploying known technology and infrastructure for a sustainable economy needs to happen quickly. Achieving pace will require difficult decisions with incomplete information. Flexible plans which can adapt to changing circumstances and drivers will need to be developed.

6 For comparative examples of infrastructure project timescales, see: Royal Academy of Engineering, A Critical Time for Energy Policy, p.13-14. [Accessed March 2020]

7 Committee on Climate Change, Net Zero Technical Report. [Accessed March 2020]

Project goals

The working group will consult widely to inform specific aspects of the project and will publish advice and commentary on a range of topics, especially those that cut across different sectors.

To ensure timeliness, the working group will release briefings and papers regularly to inform decision-making. Each will demonstrate why it is important to identify actions for sectors or technologies in the context of a system transition.

Our project aims are to:

- **Unite the engineering profession around a shared vision for decarbonising the UK.**
- **Stimulate and influence debate and discussion across civil society.**
- **Demystify the challenges of net-zero through grounded, practical evidence-based advice rooted in engineering expertise.**
- **Clarify the change needed across policy, regulation, institutions, finance and social behaviour for humans to live within the resource constraints of the planet.**
- **Recognise existing technologies and advise on possible strategies for their deployment.**
- **Spot new and radical ideas for technology use, policymaking and sustainable business models.**[8]
- **Synthesise and share international perspectives, best practice and learning.**

The working group recognises the plurality of views which exist across the engineering community at strategic level and on specific actions that are required for decarbonisation, sustainability and achieving the net zero target. We will gather and assess the engineering evidence base that underpins these issues, ensuring it is valid and robust. We will share our assessment, making it clear where there are gaps or where there are multiple options available, to assist and inform decision making. We will focus on how we can usefully and uniquely support the UK government's decarbonisation goals, and we acknowledge that final decisions will consider wider political, societal and economic factors.

8 Owens S, Petts J and Bulkeley H., 2006, *Boundary Work: Knowledge, policy and the urban environment*, Environment and Planning C: Government and Policy 2006, volume 24, pages 639.

The systems approach

A systems approach can help policymakers frame a policy question in a different way; it encourages evidence gathering that draws upon the widest, most diverse and critical perspectives leading to a 'bigger picture' view of the policy problem and how it might be tackled.

The approach enables policymakers to think about interactions between different parts of the system, and how these can combine to affect the desired outcome. A change towards a systems mindset will be required to achieve net zero, where policy areas previously approached separately or in isolation will need to be recognised as interconnected systems.

Moving from the previous target of 80% reduction in greenhouse gas emissions to net zero, **represents a big step-change**, which should not be underestimated. The current UK target, net zero territorial emissions by 2050, will require an unprecedented breadth, scale, complexity and pace of change. It involves replacing or retrofitting entire technologies, infrastructures and supply chains in advance of their anticipated end of life, including much of what is currently in development. It has implications that will extend beyond just infrastructure and technology adoption, impacting finance, regulation, institutions, behaviour change, social norms, world views, culture, and politics to name but a few.

There is no single way of 'taking a systems approach' to decarbonisation. Even for one policy challenge, there are multiple methods and tools within the field of systems science each suited to specific purposes or sets of questions. The approaches often draw upon common insights and share a common focus on understanding the whole system, recognising that it is complex, and has emergent properties that arise from the way different elements interact. This applies whether the system being studied is a town, a company, an economic sector or a rail network.

Systems practice represents a new way of understanding and approaching the complexity of how technology, infrastructure, economics, governance and, crucially, individual and social behaviours and attitudes shape the world around us, including driving unsustainable emissions and sustainable solutions.

How can systems thinking help policymakers?

In policymaking, it can be useful to view a policy problem or challenge in terms of 'hard' and 'soft' systems. 'Hard' systems refer to material/technical/infrastructure embedded in the 'soft' systems of the behaviours, attitudes, institutional structures and economics. The relationship between 'hard' and 'soft' will influence how the overall system functions, in both desirable and undesirable ways.

Systems thinking applied to policy can help to:

- **identify points of greatest leverage, where intervention will make most difference**
- **demonstrate the scale of the transition challenge**
- **reveal important synergies, interdependencies and trade-offs between different decarbonisation strategies**
- **identify incentives in the system that are working against the overall goal**
- **help account for social, cultural and behavioural factors that can act as both barriers to and levers for change**
- **reduce the risk of unintended consequences.**

Final thoughts

In this project, **the systems perspective will focus on the interdependencies between emitting sectors and take a big picture view** of individual technologies or policy strategies to study their broader impacts.

It will look at the complex relationships between sectors, technologies and policies, and the scale of coordinated, connected change that is needed to achieve net zero. The project will be guided by a systems approach that addresses the material requirements and the social, cultural and economic factors that will contribute to successful achievement of net zero.

Annex A includes a case study on the decarbonisation of homes. It draws on the expertise and knowledge of the Academy's Fellowship and partners from across the NEPC. It includes an illustrative map (*Figure 1*) that highlights the many, interdependent components that affect the decarbonisation of homes. The evidence collected directly influenced the Prime Minister's Council for Science and Technology's letter on A Systems Approach to Delivering Net Zero.

Challenges such as decarbonisation appear smaller and more manageable when broken down into constituent sectors and challenges. Without an over-arching system architecture or system transition strategy in place, there is a risk of failing to adequately account for the knock-on effects that changes in one sector will have on each other. For example, transport decarbonisation strategies will make assumptions about, and have ramifications for, requirements for houses, workplaces, energy infrastructure and vice versa.

The defining challenge for the UK on its road to achieving net zero is achieving a more holistic, or whole system, view of the decarbonisation problem, together with a realistic picture of what a net zero society should look like, to steer the transformation of multiple sectors of our economy.

List of topics

The following is a list of ideas sourced from the working group that the NEPC is interested in covering in this project, subject to resource availability. This may be through publication of papers, holding workshops, convening roundtables and commissioned work such as evidence papers and think pieces.

- **Rebuilding after COVID-19**: recommendations for a recovery which puts us on track for net zero.
- **Net zero explained**: how the UK's climate target fits into the global sustainability challenge.
- **Priority actions and upcoming decision points**: understanding which policies are 'low regrets' solutions.
- **Decarbonising construction**: tackling the operation and supply chain of one of the most difficult sectors.
- **Localised decarbonisation**: addressing climate at the local and regional level through decentralised systems planning.
- **The climate skills gap**: training and workforce requirements for an accelerated transition.
- **Powering the digital revolution**: accounting for the Internet of Things and harnessing its opportunities for decarbonisation.
- **An electric vehicle world**: the interdependencies of charging requirements on transport and home infrastructure.
- **What we've got right**: learning from our success so far.
- **Visions of 2050**: the importance of developing a clear shared goal to work towards for industry, government and the public.

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Annex A | Case study: decarbonisation of homes

The challenge of decarbonisation comes with several difficult, interconnected policy problems that traverse complex socio-technical systems. Because net zero means transformative change for all of them, it is vital for government to understand the way they interact to ensure policy decisions made in one area support, rather than undermine, the strategy taken in another. This case study illustrates how taking a systems view can help to understand and visualise the level of interdependencies and connections that exist between different sectors.

Home decarbonisation, and more broadly direct emissions from the built environment, is one of the largest and most difficult issues associated with decarbonisation. Homes accounted for 18% of territorial emissions in the UK in 2018, primarily from natural gas use for heating and cooking.[9] This figure does not include indirect emissions from electricity supply. The total emissions from this sector rose 2.8% from 2017 and have remained broadly consistent for decades.[10] Emissions from heating more broadly, including in non-residential buildings and for industrial processes, accounted for 37% of UK territorial emissions in 2016.[11]

The Royal Academy of Engineering held a workshop on 25 November 2019. Experts drawn from the Academy's Fellowship and partners across the professional engineering community came together to discuss decarbonisation of homes. The summary of the discussions is represented in the illustrative map below (Figure 1), which highlights the many interdependent components that affect the decarbonisation of homes. The output from these discussions fed directly into the Prime Minister's Council for Science and Technology's letter on A Systems Approach to Delivering Net Zero.

Other points raised during the workshop include the following:[12]

- **Retrofit of heating systems and energy efficiency measures** is dependent on economic levers and incentives, navigating a complex system of ownership and responsibilities, a highly mixed housing stock, and a significant increase in the skill base is needed to adequately and rapidly perform the retrofit.
- The accumulated waste from removal of high-carbon systems such as gas boilers creates a further environmental challenge for **recycling and repurposing**.
- As well as requiring transformed standards and design models for home energy efficiency, **new-build houses must be compatible with future heating solutions** to avoid introducing unwanted path-dependencies.
- The construction of new living places further connects to **future zero-carbon transport requirements, urbanisation, and land use and biodiversity considerations**.
- It is critical that **urgent action is taken now to ensure that newly built homes, buildings and infrastructure are compatible with a net zero world**. Buildings are being constructed now that will require retrofit and be viewed as potential liabilities within a decade.
- Widespread use of electrified heating is not straightforward with significant requirements for the generation and storage of zero carbon electricity. For example, **understanding the interaction between renewable intermittency and the daily and seasonal heating demands**. This is accompanied by an increase in electrified transport demand and uncertainty around a decentralised electricity system.
- Hydrogen heating capability is dependent on a number of factors, for example, natural gas provision, cost-effective CCS or other scalable and process efficient sources of zero carbon electricity for its production. **Rollout will require redeveloped gas grids for transport, boiler retrofit, a safety case, and public trust**.
- If hydrogen supplies are limited, **competition may arise between residential use, and industry use as feedstock and for high-temperature heating**, for which there are currently no viable zero-carbon alternatives.

9 *UK Greenhouse Gas Emissions, Provisional Figures*. BEIS, 2019.
10 *UK's Carbon Footprint 1997-2016*. DEFRA, 2019.
11 *Clean Growth: Transforming Heating - Overview of Current Evidence*. BEIS, 2018.
12 Expert stakeholder workshop held at Royal Academy of Engineering, November 2019.

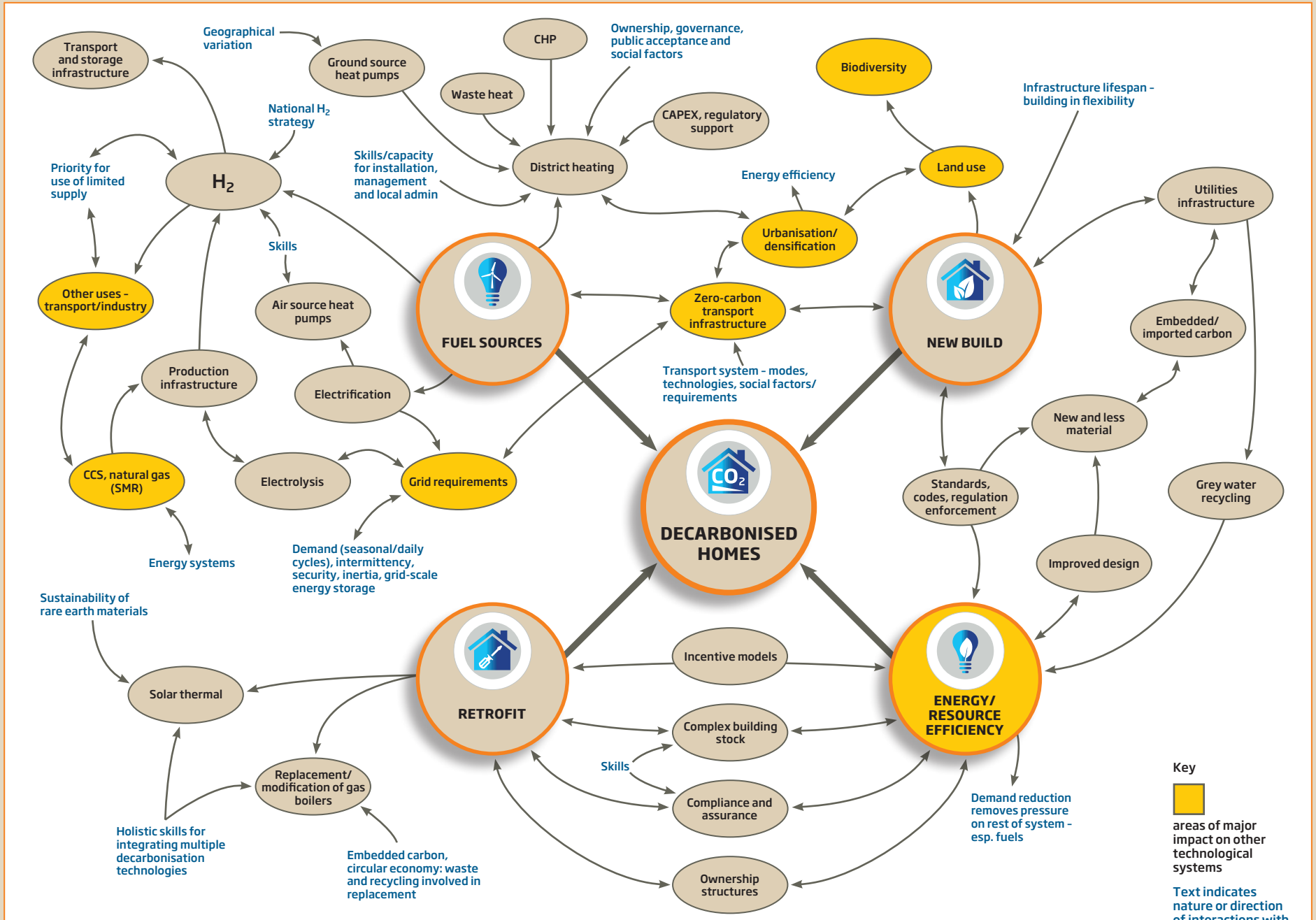

Figure 1: Synergies and interdependencies in the decarbonisation of homes

Why are residential buildings so hard to decarbonise?

Physically, the challenges associated with making an individual home compatible with net zero are reasonably well understood. A variety of technologies exist, from insulation to air-source heat pumps and hydrogen-ready boilers.

Unlike emitting sectors such as power and manufacturing, which have smaller numbers of large emitting assets, the housing sector is a good example of a system with **distributed ownership, control and responsibility**.

Many stakeholders will influence decisions on insulation, fuel choices and more, often restricted by cost, the availability of infrastructure such as gas and electricity supply, and the UK's diverse and ageing housing stock.

Our homes are emotive places; people make personal choices about where they live, and what type of home they want to live in. Factors such as warmth, security, and trust in technological safety and reliability, conservation value, historical significance and aesthetics are just some of the factors that need to be considered for both for new builds and retrofit.

Distributed ownership: system stakeholders

- Homeowners, landlords, tenants and housing/ tenant associations
- Local authorities
- Builders and developers
- Utility companies
- Regulatory and standards bodies
- Devolved governments
- Government departments/bodies including the Department for Business, Energy and Industrial Strategy (BEIS), Ministry of Housing, Communities and Local Government (MHCLG), National Infrastructure Commission (NIC), Department for Transport (DfT), and the Infrastructure and Projects Authority (IPA)
- Individual building engineers/contractors

What does a system view tell us?

Figure 1 is a simplified illustration that aims to capture the different ways that housing decarbonisation impacts, and depends upon, wider systems that at first glance might not appear to be connected; for example scale up of CCS, the UK's biodiversity, and the future of transport infrastructure.

Interacting systems such as these often evolve alongside each other gradually, and they all impact on each other. With fast transformative changes needed to transport habits, power generation and housing stock, understanding these interactions is crucial to ensuring future compatibility and preventing obsolescence.

The ideal combination of technologies for any one house depends on the characteristics of that building, but also, crucially, on the national strategy taken. From this high-level map, it is clear that many choices depend on the availability at scale of hydrogen, for which production is dependent on either additional electricity generation for electrolysis or a supply of natural gas and cost-effective CCS for zero-carbon steam methane reforming. Any strategy will have huge implications for the overall future energy system, and impact on the use of hydrogen in other sectors such as transport or manufacturing.

It also highlights that there is currently no replacement for the natural gas fuel responsible for most of home emissions and roll-out of alternatives is not straightforward. Electrification will have large implications for the generation, transmission infrastructure and reliability of supply. Home-charged electric vehicles and smart demand-side-response measures and grid-connected home or vehicle energy storage would also have an impact on demand and supply.

Diving deeper into the retrofit elements of this map, energy efficiency and gas boiler replacement/retrofit come with different, though often interconnected issues; for example, the current and future skills gap and the upskilled workforce that will be needed to install more complex home technology. It is also clear that to achieve high levels of uptake, the UK will need a range of economic levers and incentives that meet the multiple needs across the distributed ownership and control within the system.

This helicopter view of decarbonisation of homes raises the wider sustainability and environmental impacts that result from a positive policy such as net zero, including:

- **Material resource** related to mass production of components such as batteries and solar panels.
- **Circular economy**, though the recycling and disposal of redundant components like gas boilers.
- **Biodiversity**, which is significantly impacted by housing and infrastructure deployment strategies.

While it does not necessarily provide simple or easy answers, understanding systems is vital for identifying all the trade-offs associated with decisions. It can help to identify potential leverage points, or points of influence that can be used to design effective, future-proofed policy interventions across this complex landscape.

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The **National Engineering Policy Centre** connects policymakers with critical engineering expertise to inform and respond to policy issues of national importance, giving policymakers a route to advice from across the whole profession, and the profession a unified voice on shared challenges.

The Centre is an ambitious partnership, led by the Royal Academy of Engineering, between 39 different UK engineering organisations representing 450,000 engineers.

Our ambition is that the National Engineering Policy Centre will be a trusted partner for policymakers, enabling them to access excellent engineering expertise, for social and economic benefit.

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