Options | Choices | Actions

UK scenarios for a low carbon energy system transition

energy technologies institute

WELCOME

TO THE FUTURE OF LOW CARBON ENERGY IN THE UK

Contents

'UK scenarios for a low carbon energy system transition' is informed by ESME – the Energy System Modelling Environment from the Energy Technologies Institute

ESME
Energy System Modelling Environment

EXECUTIVE SUMMARY

1

The UK can achieve an affordable transition to a low carbon energy system over the next 35 years. Our modelling shows abatement costs ranging from 1-2% of GDP by 2050, with potential to achieve the lower end of this range through effective planning

2

The UK must focus on developing and proving a basket of the most promising supply and demand technology options. Developing a basket of options (rather than a single system blueprint) will help to limit inevitable implementation risks

3

Key technology priorities for the UK energy system include: bioenergy, carbon capture and storage, new nuclear, offshore wind, gaseous systems, efficiency of vehicles and efficiency/heat provision for buildings

4

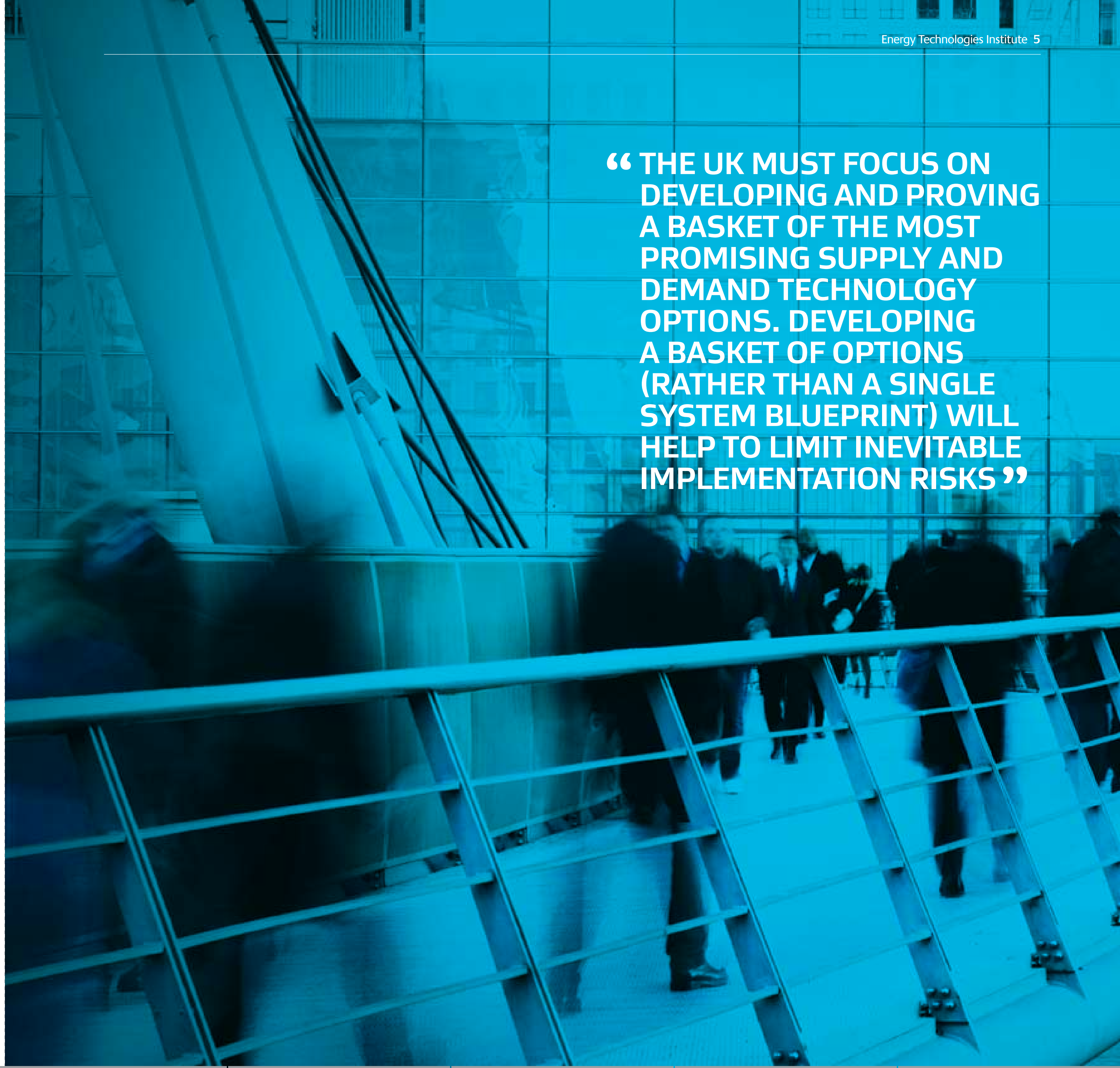
It is critical to focus resources in the next decade on preparing these options for wide-scale deployment. By the mid-2020s crucial decisions must be made regarding infrastructure design for the long-term

5

CCS and bioenergy are especially valuable. The most cost-effective system designs require zero or even "negative" emissions in sectors where decarbonisation is easiest, alleviating pressure in more difficult sectors

6

High levels of intermittent renewables in the power sector and large swings in energy demand can be accommodated at a cost, but this requires a systems level approach to storage technologies, including heat, hydrogen and natural gas in addition to electricity



“THE UK MUST FOCUS ON DEVELOPING AND PROVING A BASKET OF THE MOST PROMISING SUPPLY AND DEMAND TECHNOLOGY OPTIONS. DEVELOPING A BASKET OF OPTIONS (RATHER THAN A SINGLE SYSTEM BLUEPRINT) WILL HELP TO LIMIT INEVITABLE IMPLEMENTATION RISKS”

FOREWORD

A MESSAGE FROM THE CHIEF EXECUTIVE
DR DAVID CLARKE

The work we have undertaken at the ETI has shown the importance of a systems approach to energy planning – sectors and their infrastructure cannot be developed in isolation. Therefore one of the first acts of the ETI was to establish ESME our Energy System Modelling Environment, which is an internationally peer-reviewed national energy system design and planning tool.

The UK energy environment comprises a complex set of needs, technologies and choices. We first conceived ESME for our own technology investment purposes, but over the years it has developed into a powerful energy system model for the UK.

Our refinement and development of the model with input from our private and public sector membership has allowed us to develop illustrative scenarios for the UK's energy transition out to 2050. We present here two representative scenarios of the future which each show pathways the UK can follow, but importantly highlight the changes the UK needs to consider and make to its energy infrastructure – this is unavoidable.

We hope the scenarios inform and provoke debate, and progress thinking about how we power the UK in the future.

“ WE HOPE THE SCENARIOS INFORM AND PROVOKE DEBATE, AND PROGRESS THINKING ABOUT HOW WE POWER THE UK IN THE FUTURE ”

A MESSAGE FROM THE GOVERNMENT'S CHIEF SCIENTIFIC ADVISOR
SIR MARK WALPORT

The UK has consistently provided leadership on climate change. The Climate Change Act of 2008 was the first such legislation anywhere in the world, committing the UK to reduce emissions through a series of ever tightening carbon budgets.

In 2015, governments from across the world will meet in Paris for the latest round of negotiations towards a global deal on climate change. Time is running out and failure to act decisively will expose us all to an unacceptable and unnecessary level of risk from the worst effects of climate change.

At home we are delivering on our targets and have already implemented measures to limit the most polluting power stations, introduce more renewables onto the grid and incentivise improvements in the UK housing stock. The transition to a low carbon economy also requires strategic planning for the longer term. The ETI has supported the government by providing a strong evidence base on the options available and a modelling framework to help to underpin DECC's Carbon Plan and other decision making.

The ETI scenarios described in this booklet are a welcome addition to the discussion around UK transition. The scenarios demonstrate the crucial importance of the near-term measures designed to help us achieve our carbon budgets. At the same time they highlight the scale of the challenge ahead and the action which is required now to prepare for the next stages of our journey towards a secure, affordable low carbon energy system for the UK.

“ IN 2015, GOVERNMENTS FROM ACROSS THE WORLD WILL MEET IN PARIS FOR THE LATEST ROUND OF NEGOTIATIONS TOWARDS A GLOBAL DEAL ON CLIMATE CHANGE ”

SECTION ONE

ETI MODELLING AND SCENARIO APPROACH

1

ABOUT THE ETI

The Energy Technologies Institute is a partnership between global energy and engineering companies and the UK Government.

Its role is to act as a conduit between academia, industry and government to accelerate the development of low carbon technologies.

It brings together engineering projects that develop affordable, secure and sustainable technologies to help the UK address its long-term emissions reduction targets as well as delivering nearer term benefits.

It makes targeted investments in a portfolio of nine technology programmes across heat, power, transport and the infrastructure that links them.

ETI Members

bp | Caterpillar | EDF Energy | Rolls-Royce | Shell | EPSRC Pioneering research and skills | Department for Business Innovation & Skills | Department of Energy & Climate Change | Innovate UK Technology Strategy Board

ETI Programme Associate

Hitachi Inspire the Next

ETI STRATEGIC VIEW

The ETI strategy team works across its portfolio of nine technology programme areas and undertakes system wide energy modelling analysis to build a better understanding of the UK energy challenges. Each programme area has its own strategic insights to offer. By consolidating these insights, the ETI has developed a system wide strategic view regarding a low carbon energy system transition for the UK.

35 YEAR TRANSITION

The UK can implement an affordable 35-year transition to a low carbon energy system (1-2% of GDP) by refining, commercialising and integrating known but currently underdeveloped solutions.

CCS AND BIOENERGY

CCS and bioenergy have enormous potential and are key to delivering a low carbon future The ability (or failure) to deploy these two technologies will have a huge impact on the cost of achieving the climate change targets and on the national architecture of low carbon systems.

MAJOR INVESTMENT

The next decade is critical in preparing for transition Major investment is required to develop and prove key technology options by the mid 2020s, providing scope for economic advantage in a global market place.

FUTURE ENERGY SYSTEM

By 2025, crucial decisions must be made regarding infrastructure design for the long term to avoid wasting investment.

UK SPEND

Planned UK spend is probably sufficient if targeted properly to develop genuine deployment readiness of the most strategically valuable options on the pathway to 2050.

POLICY INTERVENTION

Significant policy intervention will be required to support key technologies with characteristics that make a pure market approach difficult e.g. CCS, bioenergy, nuclear, offshore wind, heat networks. Public sector investment has to generate investor and consumer confidence, it cannot work the other way around.

ETI ENERGY SYSTEM MODELLING

Strategic Analysis

The ETI has worked closely with its members and with project partners to develop and refine its strategic thinking. This has been supported by analysis and research activities evidenced against large scale development and demonstration projects and field trials undertaken in ETI projects.

This accumulating evidence base has been incorporated into the ETI's modelling framework.

Download
This booklet will be followed by a more in-depth guide to the modelling work behind the scenarios presented. In the meantime, for more detail on ESME and how we use it in our strategic thinking, see:
www.eti.co.uk/project/esme

ESME
Energy System Modelling Environment

Modelling Approach

The ETI has developed its Energy System Modelling Environment (ESME) – an internationally peer-reviewed national energy system design and planning capability – to identify the lowest-cost decarbonisation pathways for the UK energy system. This involves running hundreds, even thousands of simulations, exploring the variation on cost-optimal designs within a range of assumptions and constraints in order to identify robust strategies against a broad range of uncertainties.

ESME covers the whole energy system for the UK, meaning the ETI can look in detail at possible designs for infrastructure, supply and end-use technologies for heat, electricity, personal transport, freight, industry and so on.

We have tested the designs by removing and adding certain technologies and adjusting their cost and performance characteristics.

The runs allow us to understand which are the most valuable (combinations of) technologies under different conditions, which are the most robust, and which technologies act as effective insurance options in case a first choice technology fails to deliver.

The system designs produced by ESME are then stress tested by other means, for example we test the power sector designs through a 'dispatch model' that can simulate electricity supply and demand on a minute-by-minute basis.

We recognise that techno-economic optimisations are imperfect. Many low carbon solutions have benefits and drawbacks that cannot be easily represented in this fashion. That is why ETI analysis is supported by detailed research around consumer needs, environmental impacts, business models and more across our entire portfolio.

ETI INSIGHTS PAPERS

The ETI modelling work draws on insights from across our portfolio of nine technology programme areas.

Insights papers
Currently in production

- Targets, technologies, infrastructure and investments – preparing the UK for the energy transition
- Offshore Wind Insights
- Tidal Energy Insights
- Wave Energy Insights
- Decarbonising heat for UK homes
- Heat in Homes – Consumer Insights
- The role of hydrogen storage in a clean responsive power system
- Insights into the future UK Bioenergy sector – gained using the ETI's Bioenergy Value Chain Model

Download
Our insights papers are available for download from our website with many more coming soon:
www.eti.co.uk

Insights papers
Published

CCS

Carbon Capture and Storage – Potential for CCS in the UK
A demonstration of the system wide importance of CCS through its capability and flexibility to reduce carbon emissions from a large range of activities.

Optimising the location of CCS in the UK
An examination of how informed decisions about CCS infrastructure location are critical to help keep costs and risks low.

A picture of CO_2 storage in the UK – Learnings from the ETI's UKSAP and derived projects
An analysis providing estimates of the size and cost of equipping the UK with a CCS infrastructure which allows it to meet its 2050 climate change targets.

Transport

An affordable transition to sustainable and secure energy for light vehicles in the UK
An analysis of the light vehicle market and its energy supply infrastructure to define a low carbon transition path that is affordable, secure and sustainable for the UK.

Marine

Marine Energy Roadmap
A roadmap developed by the UK Energy Research Centre (UKERC) and the ETI identifying the research and development areas that need to be addressed to make marine energy cost competitive with other energy technologies.

ETI INSIGHTS COMING IN 2015/2016

Power plant siting study

Detailed analysis of the extent to which future large-scale power plant deployment in the UK (e.g. CCS, nuclear) could be constrained by site availability

Systems requirements for alternative nuclear technologies

Identification of the high-level performance requirements for small nuclear power plant focussing on the needs of the energy system, equipment operational flexibility, and the interaction of the plant with the local environment

Local engagement in UK energy systems

Quantification of the types of locally-led engagement with energy provision, and the identification of institutional changes that would support any scaling up of activity

Natural Hazards review

Identification of the combinations of natural hazards that could apply in the UK out to 2050 and beyond with guidance on how these should be taken into account in new power plant design

Heat infrastructure cost reduction opportunities

Quantification of the potential for heat infrastructure cost reduction – the innovation opportunities that exist – and its impact in terms of the national rollout of district heating infrastructures

Gas vector transition pathway analysis

Identification of the engineering challenges and technology innovation opportunities associated with large-scale gas vector transitions in the UK

Storage and flexibility

Analysis of the value of storage and flexibility as part of the transitioning energy system, and the operational considerations to deliver this value.

Understanding of market, policy and regulatory blockers to new storage technology and economic analysis of the business case for potential reforms

Network innovations

Quantifying the impact that selected innovations could have on the evolution and transition of energy networks in the UK

System wide decarbonisation policy & incentives

Analysing the implications of energy system analysis for decarbonisation policy design – with a focus on enabling carbon markets and understanding the implications for tax and fiscal policy reform

Energy market frameworks

Exploring options for low carbon energy market designs for optimal technology choice (flexible capacity, storage, network investment, demand side, etc)

Commercial & regulatory framework for CCS deployment

Continued engagement and analysis to support the creation of an enabling financial, regulatory & commercial framework for CCS sector development

Costing Preparedness

Developing a detailed analysis of the steps required over the next decade to prepare the UK for long term transition, including an assessment of the cost involved for key technologies

Transport decarbonisation policy

Analysis of policy and resource allocation to cut emissions cost-effectively

UK Bioenergy Resources

Further analysis of options to develop a bioenergy sector in the UK drawing insights from the projects in the ETI's bioenergy programme

Policy and business models for developing UK biomass

Developing a deeper understanding of business model and policy options to enable the up-scaling of a sustainable UK biomass production base, together with understanding agricultural policy options to promote efficient biomass production

HDV Transport

Development of a cost effective technology path for significantly reducing the GHG emissions from both land and marine heavy duty vehicles with consideration to real world usage. Furthermore a view on market barriers for the take up of such a technology approach

OUR SCENARIOS APPROACH

ETI Scenarios

We have used ESME and its outputs to produce scenarios for use internally, by our membership and with wider stakeholders. This is to facilitate a conversation around the potential pathways for UK decarbonisation.

In developing these scenarios we have engaged frequently with our members and stakeholders, so the outputs have been crafted in collaboration with private companies, public sector bodies, academics and other experts in energy strategy.

A variety of energy system pathways are possible to meet the UK's 2050 emissions targets. We cannot represent every possible evolution of the UK energy system in two scenarios, but the other possible outcomes that are similar to the highlighted Clockwork and Patchwork scenarios in this analysis represent a significant part of the cost effective design space.

Recent experience has shown how hard it is to forecast what will happen even over the short term, let alone out to 2050. The two scenarios described in this book should not be read as predictions or forecasts of the most probable outcomes. They are both plausible and affordable but require considerable co-ordination and planning as well as consumer and social engagement.

The two scenarios we have selected illustrate key lessons we have learned. Within the two scenarios we have captured the technologies that are likely to be important in cost effective UK system designs, as well as some that are more expensive but may have popular support.

We intend for these scenarios to stimulate debate about the choices the UK must make and the actions the country needs to take. This is not to imply that the options for the UK are restricted to a simple two-way choice. However, technologies that consistently appear across a broad range of scenarios and are resilient to sensitivity analysis warrant prioritisation in preparing for transition.

“WE HAVE USED ESME AND ITS OUTPUTS TO PRODUCE SCENARIOS FOR USE INTERNALLY, BY OUR MEMBERSHIP AND WITH WIDER STAKEHOLDERS”

“THE TWO SCENARIOS WE HAVE SELECTED ILLUSTRATE KEY LESSONS WE HAVE LEARNED. WITHIN THE TWO SCENARIOS WE HAVE CAPTURED THE TECHNOLOGIES THAT ARE LIKELY TO BE IMPORTANT IN COST EFFECTIVE UK SYSTEM DESIGNS, AS WELL AS SOME THAT ARE MORE EXPENSIVE BUT MAY HAVE POPULAR SUPPORT”

SECTION TWO

CONTEXT

The UK's Climate Change Act has established a legally binding target to reduce the UK's greenhouse gas emissions by at least 80% below the 1990 base level by 2050.

The UK has since published four carbon budgets, mandating stepwise emissions reductions of 50% below this base level by 2027.

Action so far has focused on decarbonising the UK's power sector, and to a lesser extent encouraging individual households and vehicle owners to improve their energy efficiency using today's infrastructure.

All of these actions will contribute towards meeting the carbon budgets through to 2027, but alone they are unlikely to be sufficient for meeting emissions reduction targets in the longer term.

Between 2025-2050 the country must undergo major changes in the way energy is produced, transmitted and used in buildings, transport and industry.

Decarbonisation to 2050 is achievable through widespread deployment of low carbon technologies and infrastructures which are already known, but underdeveloped. A successful transition is not reliant on improbable breakthroughs or wildcard technologies.

Still, society and consumers need to accept and ideally desire low carbon solutions. Low carbon business models will need to be viable and attractive to investors. Infrastructure and supply chains will need to be built up to deliver change at the necessary scale.

The most attractive mix of technologies will be dependent on the evolution of UK society and the global context the UK will find itself in. The country needs to provide real options through developing and proving technologies, testing new business models, building supply chains, and understanding societal needs. This will allow for informed decision-making.

2

RISKS AND UNCERTAINTIES

There are two key dimensions in developing a strategy to mitigate climate change:

» In a global context, will mitigation action progress steadily, or will a more limited initial response necessitate a rapid transition to a major commitment of resources later?

» Domestically, what is the right balance between solutions which capture popular support and those which can be combined into the most cost-effective plan?

Mitigation Progress

Our view at the ETI is that international action will accelerate as extreme climate events become more commonplace and successful lawsuits are brought for damages. Societies that have prepared for integrated, whole-system solutions will enjoy an advantage. Those that have not will likely suffer from unfavourable terms of trade and lawsuits against their major companies.

We discuss the risks of delayed action, while our scenarios both adopt a timely and steady approach to decarbonisation.

Technology Choices

Societal values are central to the choices that national decision-makers can legitimately make between alternative low carbon pathways. Developing an evidence base for the relative costs and benefits of different solutions can help inform societal acceptance, but ultimately where social values and perceptions clash with economic assessment, a balance will have to be struck and choices made.

Our two scenarios explore this dimension through the emergence of distinct social and political landscapes and the technology choices that might be associated with those.

THE COST OF STANDING STILL

Falling behind

Abandoning or weakening climate targets in the near term would represent a lost opportunity for the UK to position itself as a market leader for low carbon technology. Delays produce a very bleak outcome where the UK is trying to play catch-up without effective preparation, suffering from unattractive terms of trade through carbon price penalties and over-reliant on the skills and products of other nations to meet its needs.

In our modelling work we have explored a number of pathways in which the UK slips from its carbon budget trajectory, meaning we are producing an excess of emissions by the mid-2020s. Getting back on track after losing momentum would require a rapid reduction in energy demand, coupled with a radical transformation of the entire energy infrastructure in as little as 15 years (around the life of an average family car).

Even with highly optimistic rate-of-change assumptions, our techno-economic model fails to meet the 2050 targets under these conditions.

Lack of ambition

Missing the carbon budgets outright is not the only risk the country could face. It is quite possible to imagine a future where the UK meets the interim targets out to 2027, but fails to establish a proven, demonstrated plan for how deeper cuts are to be achieved in the long term.

Our modelling work suggests the UK could meet existing carbon budgets out to 2027 largely through existing policies to deliver a pipeline of low carbon projects, supported by improved efficiency in the housing stock and turnover of incumbent technologies such as gas boilers and internal combustion engines.

Over the long term, these technologies will continue to deliver efficiency savings which can contribute to further emissions reduction. But these improvements will level off over time. Eventually, the residual emissions resulting from even the most efficient models of these technologies will be too high, and low carbon solutions will be required that can drive emissions down more aggressively.

It would be a mistake to think the country can wait until efficiency measures have been exhausted before we turn to alternative, low carbon solutions. If the UK waits until the mid 2020s, a lack of supply chain capacity is likely to mean that preferred solutions have to be supplemented by second-choice technologies at far greater expense. In our model, failure to prepare properly leads to a significant escalation in the cost of abatement action by 2050 (to around 3-4% of GDP).

> “ IN OUR MODEL, FAILURE TO PREPARE PROPERLY LEADS TO A SIGNIFICANT ESCALATION IN THE COST OF ABATEMENT ACTION BY 2050 (TO AROUND 3-4% OF GDP) ”

THE NEXT DECADE

Over the course of the next decade, the UK must prepare for a comprehensive energy transition out to 2050. There should be no let-up in action to meet forthcoming emissions budgets, but incremental change will not suffice for the long term. At a certain point, decisions have to be made on a clear direction of travel so that new infrastructure can be planned and investments made in a timely fashion.

There is always a risk that some technologies will fail to deliver. Even those that are proven from a technological standpoint may fail to gain the popular support necessary to persuade policy makers to back them. A number of solutions therefore have to be explored in parallel until it is clear which ones represent genuine options for the UK.

The ETI is developing strategies for ensuring UK preparedness by 2025. By then, we need to be in a position to have assessed the available options and to allow for a series of difficult choices to be made regarding long term infrastructure needs. Any indecision would prove costly. Duplicating infrastructure or committing to one path then switching tracks will be unnecessarily expensive and wasteful – of money, time and talent.

Decisive leadership will also boost global efforts by showcasing solutions that will support decarbonisation of much larger nations with more significant emissions. Where the UK has gained a market lead in successful technologies, export opportunities offer a long term benefit to the UK economy.

Our two scenarios, Clockwork and Patchwork, follow distinct pathways as technology development and societal choices play out differently.

“OUR TWO SCENARIOS, CLOCKWORK AND PATCHWORK, FOLLOW DISTINCT PATHWAYS AS TECHNOLOGY DEVELOPMENT AND SOCIETAL CHOICES PLAY OUT DIFFERENTLY”

2050

Over the course of the next decade, the UK must prepare for a comprehensive energy transition out to 2050. There should be no let-up in action to meet forthcoming emissions budgets, but incremental change will not suffice for the long term.

SECTION THREE

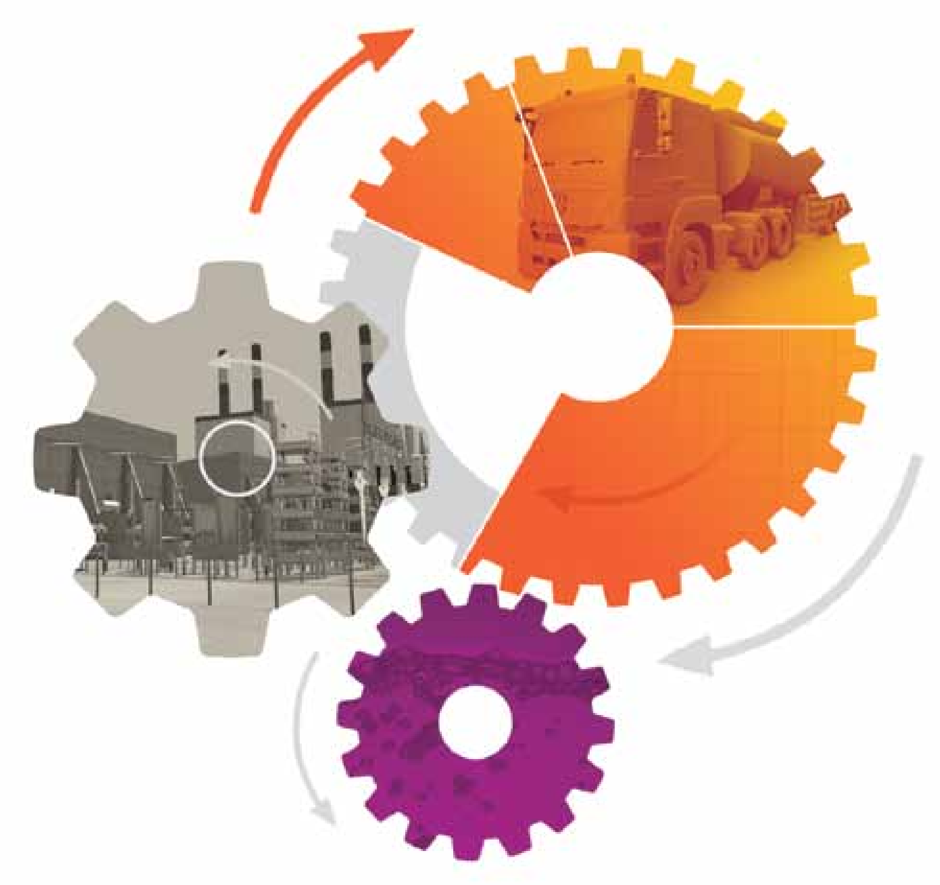
ETI SCENARIOS

3

INTRODUCING THE
SCENARIOS

CLOCKWORK

Well-coordinated, long term investments allow new energy infrastructure to be installed like clockwork. The regular build of new nuclear, CCS plants and renewables ensures a steady decarbonisation of the power sector. National-level planning enables the deployment of large-scale district heating networks, with the local gas distribution network retiring incrementally from 2040 onwards. By contrast, due to a strong role for emissions offsetting, the transportation system remains in the earlier stages of a transition and people and companies continue to buy and use vehicles in a similar way to today, albeit with regulation and innovation continuing to improve their efficiency.



PATCHWORK

With central government taking less of a leading role, a patchwork of distinct energy strategies develops at a regional level. Society becomes more actively engaged in decarbonisation, partly by choice and partly in response to higher costs. Popular attention is paid to other social and environmental values, influencing decision-making. There is a more limited role for emissions offsetting, meaning more extensive decarbonisation across all sectors, including transport. Cities and regions compete for central support to meet energy needs which is tailored to local preferences and resources. Over time central government begins to integrate the patchwork of networks to provide national solutions.

KEY CHARACTERISTICS
CLOCKWORK

POWER	» The policy framework supports large scale investments in CCS and nuclear. Clarity over the role of CCS enables early investment in "outsized" infrastructure and investor support for follow-on CCS projects » The current pipeline of renewables projects are delivered out to 2020 and capacity is maintained on a replacement basis until new capacity is added in the 2040s » Hydrogen for peaking plants is produced from biomass with CCS, providing system benefits including negative emissions » The capacity of nuclear, CCS and renewables is evenly balanced by 2050
HEAT	» A national framework for large scale district heating is introduced, enabled in part by waste heat from thermal power plants » A phased shutdown of the local gas distribution network from the 2040s encourages the uptake of district heating schemes » Subsidies are provided for heat pumps and efficiency improvements to speed up rural and suburban decarbonisation
TRANSPORT	» A steady tightening of EU vehicle efficiency targets for new cars is met through the uptake of hybrid and plug-in hybrid vehicles » The introduction of "soft" incentives such as road tax or congestion charge concessions for low-carbon vehicles » Emissions reduction of freight is market-led, driven by cost of liquid fuels

Institutional Mandate
A national planning approach establishes a framework for energy system decision-making. There is societal acceptance of chosen solutions.

National Scale Infrastructure
A focus is placed on national co-ordination of supply-side generation and shared infrastructure.

Carbon Offsetting
Realising the system-wide value of CCS and biomass in generating negative emissions, provides headroom for other sectors to postpone expensive decarbonisation decisions.

Phased Decarbonisation
Emissions reduction is led by action in the power sector, followed by buildings and finally transport, where regulation drives incremental efficiency improvements in vehicles, including through adoption of plug-in hybrids.

KEY CHARACTERISTICS
PATCHWORK

POWER	» Renewables find support at all levels of society: central government backs large scale projects such as offshore wind, while local authorities and communities support combined heat and power, onshore wind and solar » Initially, there is uncertainty over the role of nuclear and CCS due to a growing focus on renewables. This dampens investor appetite and limits the co-ordination of infrastructure planning » Later on, CCS deployment picks up, enabling clean hydrogen production from a mixture of biomass and coal, although biomass uptake is limited by societal concerns about land-use change and biodiversity as well as by market failures
HEAT	» There is "grassroots" support for small and medium scale district heating projects, coupled with private sector and local authority investment » A mixture of changing attitudes and high energy costs cause the growth in average indoor temperature to level off from 2030 » There is improved efficiency of housing stock through selective the retrofit of existing homes, and with apartments increasingly dominating the market for new builds
TRANSPORT	» Greater urbanisation and modal shift means slower growth in new car sales, particularly for large cars » Some cities set more aggressive vehicle efficiency targets as part of their measures to improve urban air quality » Freight transport experiences a market-led reduction in emissions due to liquid fuel costs » Market-led emissions reduction of freight

Societal Engagement
Alongside decarbonisation, popular concerns over other social and environmental values (including land use and air quality) influence decisions taken on energy system planning at a local level.

Multi-Scale Infrastructure
A mixture of national, regional and local approaches continue to deliver a patchwork of low carbon energy infrastructure and supply, with active societal engagement.

Extensive Renewables
A renewables-heavy solution to energy supply is dominated by offshore wind and supported by smaller-scale technologies including the continued growth of solar.

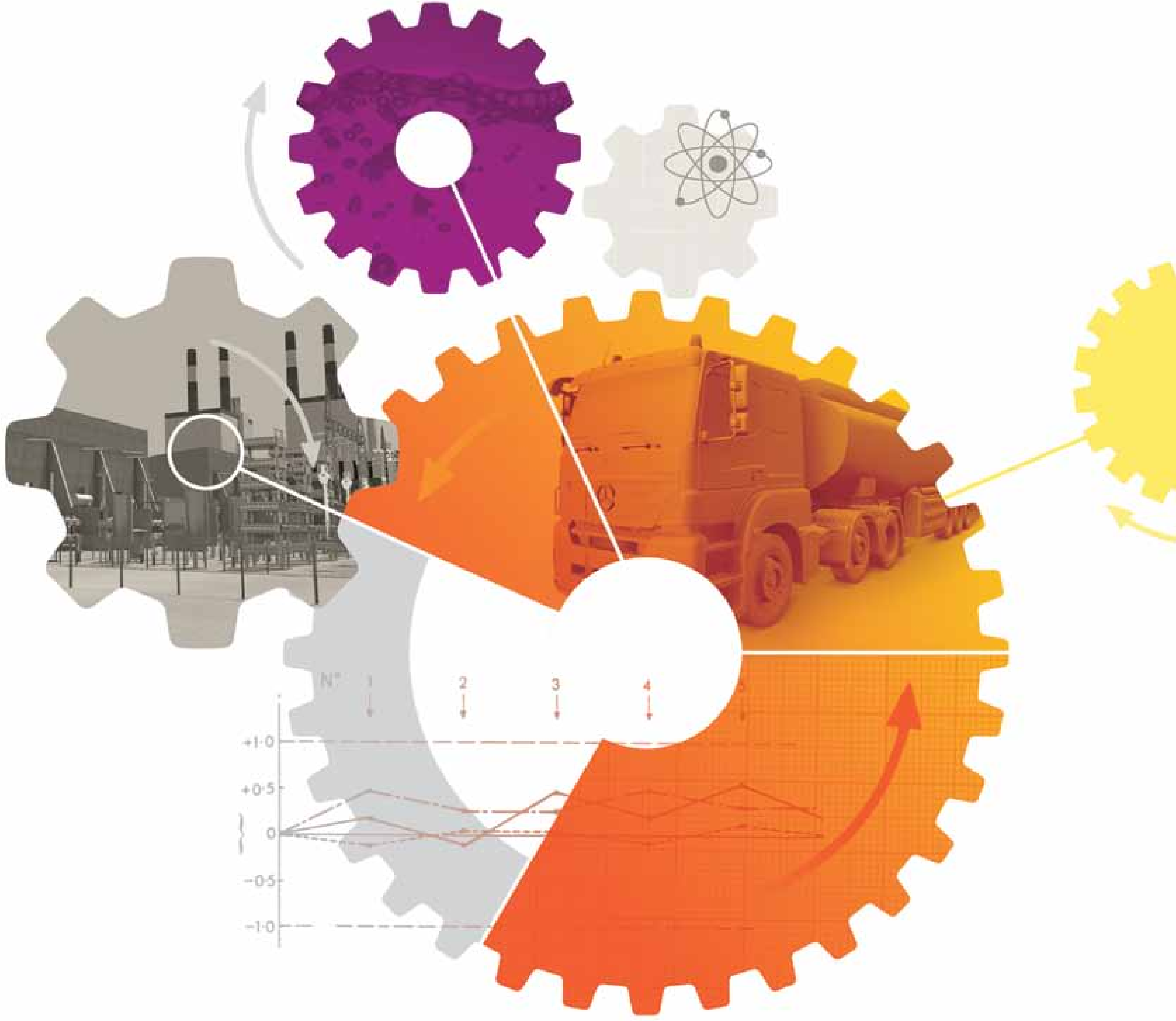
Parallel Decarbonisation
Transformation of the power sector is followed by extensive, parallel abatement action across buildings and transportation, with a substantial uptake of hydrogen fuel cell vehicles and plug-in hybrids.

CLOCKWORK

Clockwork describes a UK that continues on a socio-economic path that started pre-credit crunch. Growth comes from a mixture of services and value-added industries. Policy-making continues to be relatively centralised.

There are significant, well-planned investments in national-scale infrastructure and technologies. This reduces the burden of costs on individual homeowners and society as a whole. Policy-makers play a key role in de-risking investments by providing stable and supportive regulation providing clarity over the role different technologies have to play and the co-ordination of shared infrastructure.

- The combination of CCS and biomass creates “negative emissions” which provides headroom for other sectors and produces hydrogen for use in industry and electricity peaking plant
- There is a phase out of local gas distribution networks in the long-term
- Decarbonisation has to be balanced against two other priorities: minimising disruption to lifestyles and facilitating economic growth – creating a focus on solutions that are likely to be cheaper from an overall systems perspective
- By 2050 the capacity from nuclear, CCS and renewables is evenly balanced
- Nuclear capacity would require the development of two or three operating plants by 2025
- Aggregate power sector build rates of 2.5GW/yr to 2030, 4.5GW/yr to 2050
- Strong investment required in the electricity transmission grid to move energy from production to demand centres
- Renewables growth is scaled back
- Switching from gas boilers may impact on the welfare of some households
- Upfront investment is needed including piping for heat networks and potential reconfiguring of power plants to supply waste heat
- Mind-set change is required around public attitudes towards district heating
- Early notification and engagement necessary if switching from a local gas distribution grid
- A decline in liquid fuel sales puts the viability of current petrol infrastructure in jeopardy
- Cost of the Clockwork scenario is smaller – due to the stronger role for negative emissions relative to Patchwork



CLOCKWORK
KEY FEATURES

SECTOR HIGHLIGHTS

Electricity generation investments over the next decade or so enable a mix of nuclear, gas with CCS and offshore wind to power the grid. Committed investment in CCS also provides a foundation for a well-developed hydrogen infrastructure in the 2030s. Hydrogen is produced from UK biomass, due to supportive land use and agricultural policies, and from imports via a functioning international biomass market. This combination of CCS and biomass creates 'negative emissions' which provides headroom for other sectors and allows industry and electricity peaking plant to burn hydrogen instead of unabated natural gas.

For heat in homes and public/commercial premises, coordinated investment in district heating schemes allows for a rapid decarbonisation. Outside of urban and suburban areas government schemes encourage households to substitute oil and gas boilers with heat pumps and biomass boilers. To encourage take-up of these new schemes, the government announces an intent to phase out local gas distribution networks in the long-term, while still ensuring reliable, affordable heating for everyone.

These investments mean that any changeover of vehicles to ultra-low carbon models can take place more slowly. A combination of increasing cost-competitiveness and financial incentives enables a steady adoption of hybrid and later plug-in hybrid cars.

POWER | HEAT | TRANSPORT | INDUSTRY

CLOCKWORK
UK SOCIETY

People and places
By 2050 the UK remains one of the largest countries in Western Europe with 76 million people. The South East of England continues to be the economic centre of gravity, and the working age population is concentrated there. As more workers migrate towards the South East, society elsewhere is more aged and urbanisation becomes more muted.

Earning a living
Services and value-added industries are the main driver of economic growth. London maintains its status as a key global financial and business centre. Industrial output grows, with the mix continuing to shift towards value-added products. Business-friendly policy decisions and structural advantages (e.g. large base of knowledge workers) enable the sustained growth of value-added industries. Energy and labour intensive industries continue to decline and move offshore.

Lifestyles
Increasing disposable incomes and confidence about the future of the economy drives increased household spending across the UK. Prosperity remains largely synonymous with asset ownership and consumption. More families aspire towards suburban detached houses, car ownership, modern conveniences (e.g. air-conditioning), expensive gadgets and recreational travel within and outside the UK.

Societal engagement
Households are prepared to pay for carbon abatement where the costs are passed on to them (e.g. taxes or bills) but are less inclined to proactively adjust their behaviour beyond those changes mediated through market measures. The government therefore has a strong mandate to introduce comprehensive decarbonisation measures that spread the cost across the whole of society.

What matters
Decarbonisation has to be balanced against two other priorities: minimising disruption to lifestyles and facilitating economic growth. These priorities create a focus on solutions that are likely to be cheaper from an overall systems perspective. Some of these solutions are seen by special interest groups as compromising on other social and environmental values.

" DECARBONISATION HAS TO BE BALANCED AGAINST TWO OTHER PRIORITIES: MINIMISING DISRUPTION TO LIFESTYLES AND FACILITATING ECONOMIC GROWTH. THESE PRIORITIES CREATE A FOCUS ON SOLUTIONS THAT ARE LIKELY TO BE CHEAPER FROM AN OVERALL SYSTEMS PERSPECTIVE "

CLOCKWORK

POWER SECTOR

In Clockwork, near-term emissions regulations spur the shift away from conventional coal towards cleaner technologies, with coal plants nearly all shut down by the 2020s. Unabated gas usage declines, but it continues to play an important role for a period of time as peaking capacity before being replaced by hydrogen, which is produced from biomass with CCS.

Nuclear provides the main baseload supply under the government's decarbonisation policy. Although the public remains ambivalent, commitment to new nuclear capacity through the establishment of a clear regulatory and financial framework creates an attractive environment for investors. This results in a total of 40GW of nuclear power capacity by 2050.

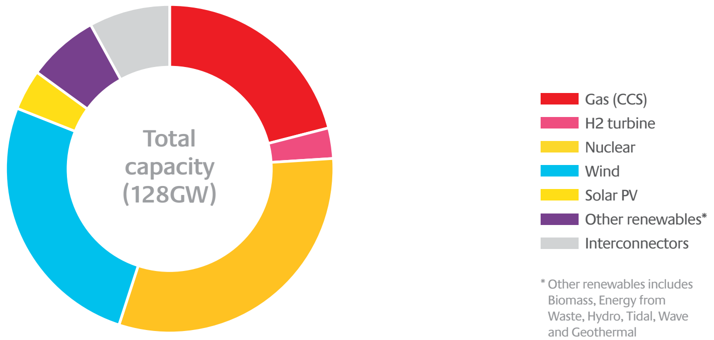
A clear role for CCS in government policy leads to the development of follow-on projects beyond the UK CCS commercialisation competition. Co-ordinated planning of shared infrastructure allows for investment in initially "outsized" CCS pipelines and stores by 2030. This allows for the rapid expansion of CCS plants at ever-reducing cost.

The higher system cost of renewables and the effective delivery of other power sources means there is less appetite to support further investment in this area. Existing projects go ahead, and are maintained throughout resulting in around 20GW wind capacity and 5GW of solar from 2020-2040.

More stringent emissions targets in later decades and transition planning for the second half of the century sees a higher renewables deployment in the 2040s, including from new sources such as tidal power. By 2050 the capacity from nuclear, CCS and renewables is reasonably balanced.

"BY 2050 THE CAPACITY FROM NUCLEAR, CCS AND RENEWABLES IS REASONABLY BALANCED"

2050 Electricity capacity



* Other renewables includes Biomass, Energy from Waste, Hydro, Tidal, Wave and Geothermal

CLOCKWORK

POWER SECTOR IMPLICATIONS

Issues and Implications

- To have confidence that 40GW of new nuclear is achievable in the long run would require the development of two or three operating plants by 2025. Supply chains will need to be built up rapidly to support a sustained rollout over the period to 2050
- Early commercialisation of CCS is also essential in this scenario, with the development of 2-3GW power plants built around two or three hubs, and the appraisal of approximately seven CO_2 stores by the mid 2020s
- Due to rolling replacement of existing stock and additional capacity requirements, Clockwork sees aggregate power sector build rates of 2.5GW/yr to 2030, followed by 4.5GW/yr to 2050
- Regional concentration of electricity generation into a small number of large scale plants looks very similar to today. But where old sites are decommissioned in favour of new sites elsewhere, this may lead to a shift in costs and benefits that needs to be managed, i.e. employment and environmental risk
- This scenario implies renewables growth is scaled back, but requires ongoing development and supply chain capability to maintain installed capacity and to enable further deployment after 2040 when costs are reduced significantly
- Given the role for negative emissions from biomass, this scenario would require the design and implementation of emissions trading frameworks to enable proper accounting of negative emissions across the UK energy system, and procedures to assure the wider sustainability of domestic and imported biomass

2025

To ensure such a large capacity of nuclear is achievable in the long run would require the development of two or three operating plants by 2025. Supply chains will need to be built up rapidly to support a sustained rollout over the period to 2050

CLOCKWORK

HEAT SECTOR

In Clockwork, activity to decarbonise the building sector becomes increasingly important as abatement action undertaken here is generally cheaper than in transport.

There is an immediate focus on targeting simple efficiency measures. In rural areas there are initiatives to promote substitution of biomass boilers and heat pumps in place of oil boilers. In new developments building codes promote or mandate the use of district heating or heat pumps. In the rest of the housing stock, although gas boilers continue to be the norm, early pilot schemes and demonstration projects pave the way for large scale transition.

From the 2030s, a comprehensive rollout of district heating gets underway, made possible through government regulation to facilitate co-ordination between utilities, consumers and new district heating companies. Waste heat from large power plants is used to supply some of these district heating schemes, but alternative heat sources may be available where this is not feasible (e.g. geothermal, marine heat pumps).

In rural and suburban areas outside the reach of district heating schemes, heat pumps are heavily promoted.

With new options available, the government signals a long-term intention to phase out local gas distribution networks from the 2040s onwards. This further encourages switchover. By 2050 heat pumps and district heating provide the bulk of heat supply, supplemented by direct electric heating, with gas relegated to a backup role.

Out to 2050 indoor temperatures continue to increase to an average of 21°C, providing improved comfort and health benefits. This is supported by improvements in the thermal quality of buildings, as whole-house retrofit packages are (selectively) applied across the housing stock.

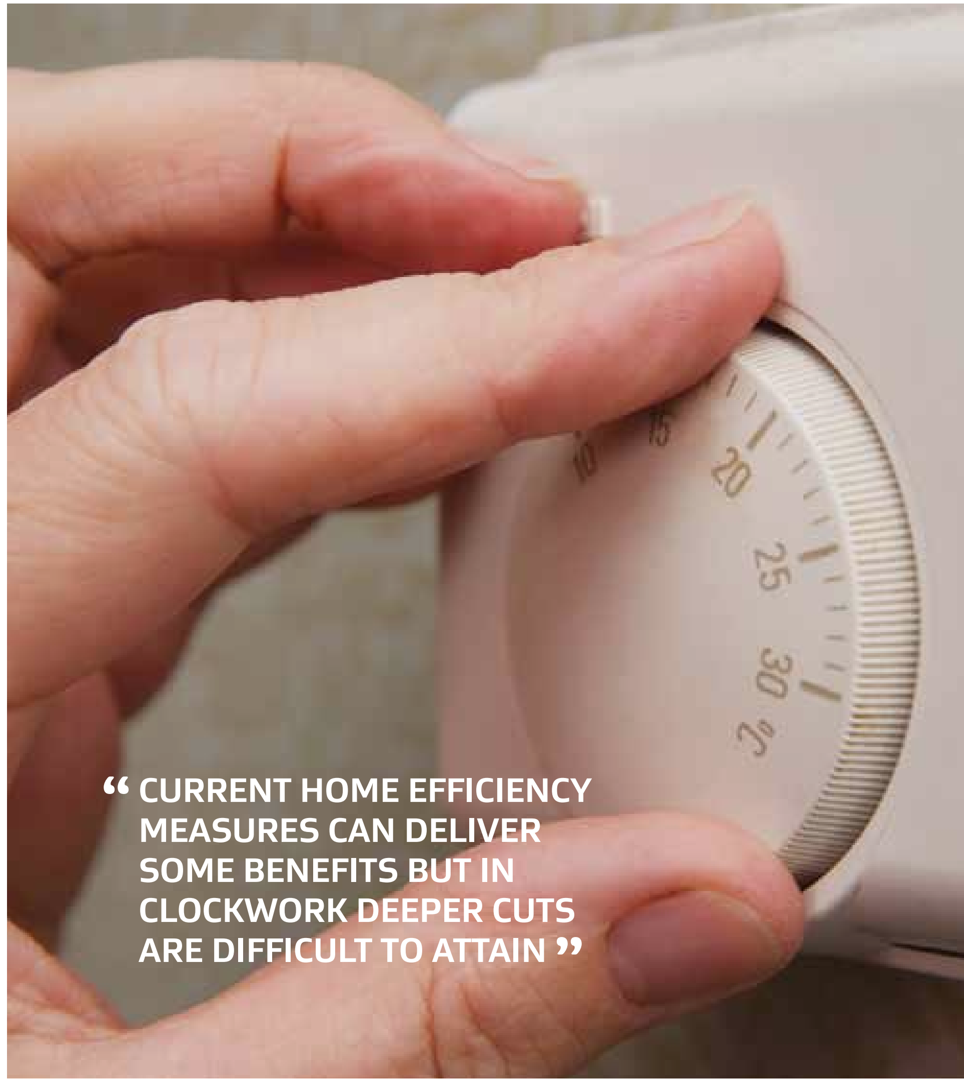
“BY 2050 HEAT PUMPS AND DISTRICT HEATING PROVIDE THE BULK OF HEAT SUPPLY, SUPPLEMENTED BY DIRECT ELECTRIC HEATING, WITH GAS RELEGATED TO A BACKUP ROLE”

CLOCKWORK

HEAT SECTOR IMPLICATIONS

Issues and Implications

- Switching away from gas boilers may impact on the welfare of some households who will need support
- District heating companies may need to be regulated given their potential monopoly position
- Current home efficiency measures can deliver some benefits but in Clockwork deeper cuts are difficult to attain without expensive whole package retrofits driven by a carbon price after 2040
- Significant upfront infrastructure investment is needed including piping and configuring of power plants to supply waste heat
- The government would need to provide a strong commitment to building shared infrastructure along with financial incentives to de-risk private sector investment and counter party risks
- A mind-set change is also required around public attitudes towards district heating, as has been achieved in places like Copenhagen
- Early public notification and engagement is necessary if switching away from a local gas distribution grid



CLOCKWORK

TRANSPORT SECTOR

In Clockwork, well planned investments in decarbonising power and heating together with a strong role for negative emissions facilitates a more gradual approach to addressing transport emissions. Improved vehicle efficiency accounts for the majority of abatement in the short term.

Hybrid sales are spurred on by EU vehicle emissions targets and supported by financial incentives such as road tax discounts. Hybrids enter mass production as manufacturers are tasked with improving fleet efficiencies. The resulting cost-competitiveness makes hybrids more attractive to consumers and market share grows significantly.

At the same time, the efficiency of conventional internal combustion engines (ICE) improves. This prolongs their presence in the vehicle fleet, although sales drop away by 2040.

Plug-in hybrid electric vehicles (PHEVs) become increasingly popular as the technology matures. They become more cost-competitive, offering comparable or greater utility to traditional ICE cars. Improvements in battery efficiency and chemistry enables a shift to PHEVs with longer electric ranges in later decades.

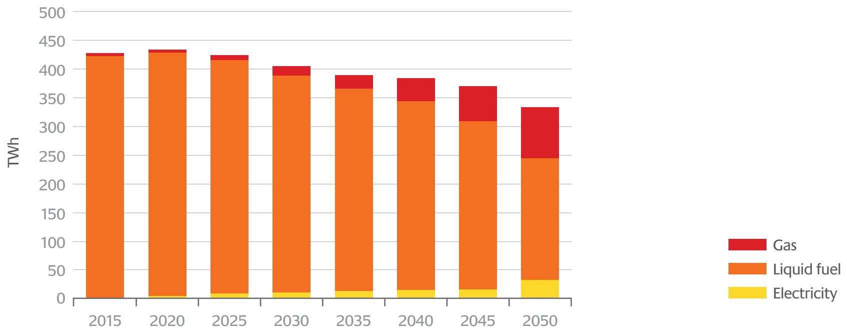
The expansion of the vehicle-charging infrastructure and the lower cost of electricity relative to liquid fuel encourages a similar uptake of PHEVs for light goods vehicles (LGVs) from the 2030s onwards.

In contrast, the relative expense of hydrogen cars and the infrastructure needed to support them means they remain unattractive in a UK context.

Within heavy goods vehicles (HGVs), liquid fuel remains the dominant solution in the medium term. In later decades more advanced gas-fuelled hybrid vehicles become increasingly competitive in light of the high carbon price and account for the majority of the fleet by 2050.

Road Transport Fuel Consumption

Plug-in Hybrids lead to increased electricity consumption in light vehicles, while gas becomes increasingly important for heavy duty vehicles. Consumption of petrol and diesel declines to half of current levels by 2050.

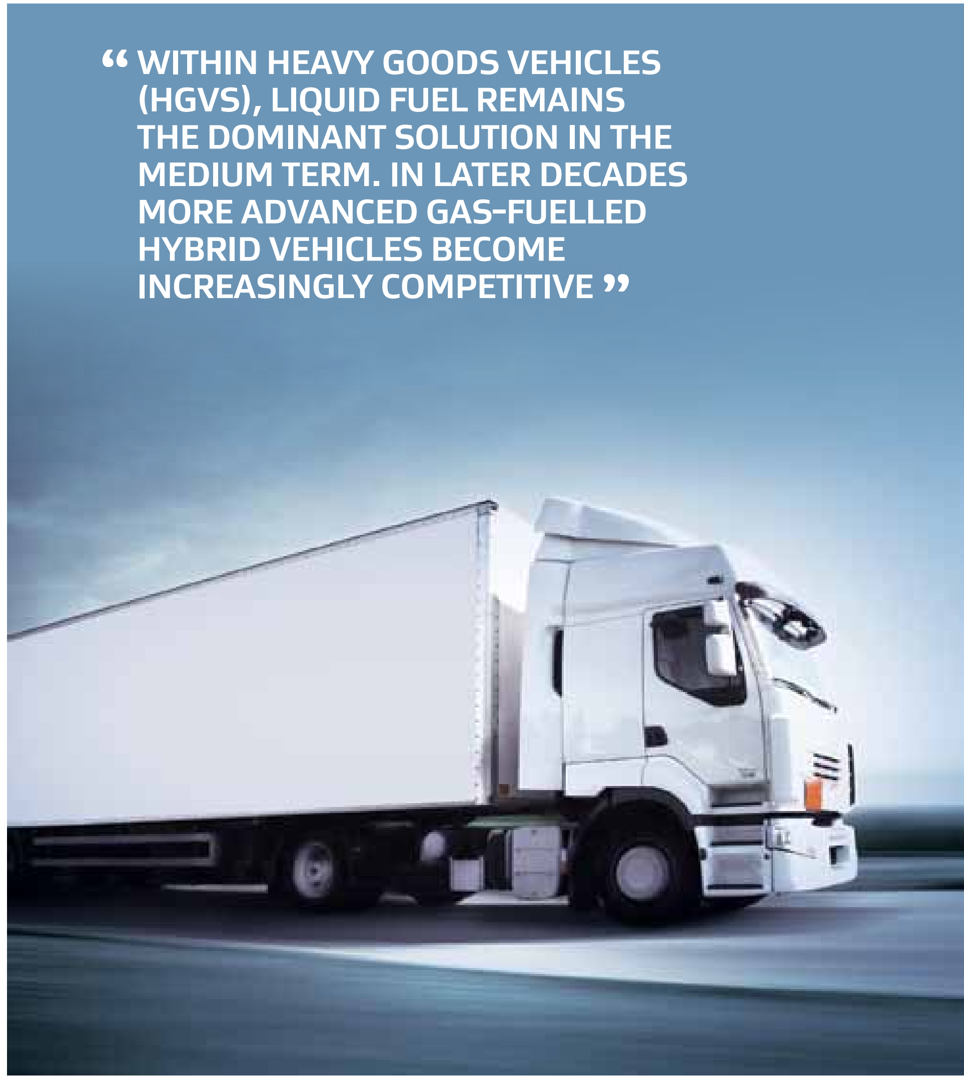


CLOCKWORK

TRANSPORT SECTOR IMPLICATIONS

Issues and Implications

- As liquid fuel sales decline the viability of the current petrol/diesel infrastructure could be in jeopardy. Substantial support may be required if the geographical coverage of the refuelling network is to be maintained
- Households which do not transfer to low carbon vehicles will have to pay premiums for liquid fuel due to carbon taxes and infrastructure costs. Policy efforts may be required to ensure that this does not fall disproportionately on the poor
- As the sector shifts away from ICE cars and conventional hybrids, their second hand value will decline, acting as an impediment to switching
- Electricity distribution regulatory framework may need to be adapted to allow for efficient network upgrades and infrastructure roll-out



CLOCKWORK

INDUSTRY SECTOR

Clockwork has a larger industry sector by 2050 compared to today. The composition shifts in favour of high-value added products. Ongoing efficiency improvements lead to a slight drop in total fuel use.

A long term strategy for CCS translates into outsized infrastructure investment. This means there is significant scope for industrial emitters located near to CO_2 trunk lines to piggy-back on existing infrastructure to help decarbonisation. From 2030, around 7-8MtCO_2 is being captured annually from CCS in industry.

In many other cases where CCS is not cost-effective, industrial emitters increase the mix of biomass in their energy supply (i.e. retrofitting on-site combustion to burn biomass).

Over the long term there is a broad switch to hydrogen combustion. Some of the larger sites located near to CCS infrastructure install biomass-to-H2 plants on site. Other industry users purchase hydrogen from these producers.

It is assumed that a significant share of industry cannot be directly decarbonised (by switching to low carbon fuels or electricity). These companies are assumed to purchase credits to offset their emissions against other sectors of the UK economy.

“AROUND 7-8MTCO$_2$ IS BEING CAPTURED ANNUALLY FROM CCS IN INDUSTRY. WHERE CCS IS NOT COST-EFFECTIVE, INDUSTRIAL EMITTERS INCREASE THE MIX OF BIOMASS IN THEIR ENERGY SUPPLY. OTHER INDUSTRIAL USERS PURCHASE HYDROGEN”

PATCHWORK

Patchwork describes a UK that builds on its strengths as a global innovator of services and knowledge-based industries. People are attracted to urban centres with good amenities and rapid transport links between an increasingly dominant core of hub cities.

Central government uses high carbon taxes, regulation and media campaigns to restrain growth in the demand for private transport and heating, and to encourage the adoption of low carbon solutions. Taxes are recycled to support the most vulnerable in society. The hub cities become centres of innovation for transport-sharing schemes together with new models for the shared development of, and investment in, local heat and power infrastructure.

Decisions on climate change action are seen as part of an overall package of societal values and beliefs in which other concerns such as land use, biodiversity, and air pollution all have influence over local decision-making.

- Affordable carbon abatement is a priority but it is viewed through a broader lens of sustainability and social values
- Renewables grow to account for the majority of electricity generation
- Intermittency of renewables implies significant backup capacity is required
- Unprecedented build rates to keep up with increasing capacity – averages 4GW/yr to 2030 then 7.5GW/yr to 2050
- With excess of 75GW of wind capacity, there are many hours of the year when electricity supply greatly exceeds demand
- Heat pumps grow steadily to supply the majority of residential heat demand by 2050
- Electric heating becomes increasingly important as a source of back-up supply of heat by 2050
- Support for whole-house retrofits and heat storage will be needed in tandem with heat pumps
- Series of electricity network upgrades and hydrogen infrastructure installations are required
- Least affluent in society who depend on older, higher emitting cars will be most susceptible to tightening emissions standards
- UK based refineries are likely to shut as petrol usage drops

PATCHWORK

KEY FEATURES

SECTOR HIGHLIGHTS

Engaged citizens are vocal in their support for offshore wind and other renewable energy. As a result the electricity grid is more diversified and distributed with a mix of different renewable sources, some nuclear and – post 2030 – hydrogen and gas with CCS.

Some cities implement district heating schemes based on local sources (gas and biomass CHP, geothermal, marine-source heat pumps). Slowly, these expand and merge to take advantage of scale, forming city-wide heating networks. In a handful of locations, the gas grid is phased out entirely by 2050.

Interest from consumers and businesses, in tandem with vehicle efficiency regulations, helps to drive increasing adoption of plug-in hybrid vehicles in the near term. Hydrogen vehicles begin to be adopted by businesses with return-to-base fleets (e.g. universities, taxis and delivery firms), where infrastructure can be built up privately. Eventually central government is pressured into creating a national transport infrastructure strategy which allows these networks to expand and merge, allowing participation by households.

POWER | HEAT | TRANSPORT | INDUSTRY

PATCHWORK

UK SOCIETY

People and places

Economic activity concentrates in London and in other large cities across the country. As the benefits of globalisation and growth become more distributed around the UK, there is increased immigration adding more workers to the population and slowing the ageing of society. By 2050 the UK is still among the largest countries in Europe with 79 million people.

Earning a living

New businesses emerge providing innovative solutions that boost productivity for many service-related activities. Industry continues to flourish in a few regions seeking to build on their industrial heritage and skills base. At an aggregate level, the overall labour mix continues to shift away from heavy industries in favour of high-tech and specialist manufacturing and knowledge-based sectors.

Lifestyles

Increasing household income drives greater spending and consumption, including on international flights. Enabling services and lifestyle changes create new patterns of demand and behaviour. The growth in car ownership slows as a result of more urban living (and increased vehicle costs). This encourages the uptake of car-pooling and sharing services. Public transport demand increases, spurring investment in trams, buses, and light rail / metro systems. While people continue to seek increased comfort in homes, average indoor temperatures level off by 2030.

Societal engagement

Households are more directly involved in mitigating their carbon footprint and many are willing to undergo considerable personal inconvenience during the transition. In some cases innovative business models facilitate coordination within communities.

Active engagement extends to the private sector. More companies begin to use green measures as a point of differentiation, creating consumer choice enabling further engagement in a virtuous cycle.

What matters

In this scenario, affordable carbon abatement is a priority, but it is viewed through a broader lens of sustainability and social values. Society is active and engaged in reducing its carbon footprint, but local decision making is also influenced by public attitudes on green issues such as biodiversity land use and clean air.

“ IN THIS SCENARIO, AFFORDABLE CARBON ABATEMENT IS A PRIORITY, BUT IT IS VIEWED THROUGH A BROADER LENS OF SUSTAINABILITY AND SOCIAL VALUES ”

PATCHWORK
POWER SECTOR

In Patchwork, action and leadership to decarbonise the electricity grid occurs on multiple levels – central government targets, regional decisions, and individual household choices. Decision-makers have different sets of priorities, with regions and households tending to balance decarbonisation alongside other environmental priorities.

With greater societal engagement comes a bias towards renewables and a preference for projects that fit with local needs. Communities play an active part in the growth of renewables, with a significant uptake of micro and ground mounted solar. Central government does have a role in developing a support framework for national scale projects where others can't, such as in offshore wind.

As a result, renewables grow to account for the majority of electricity generation.

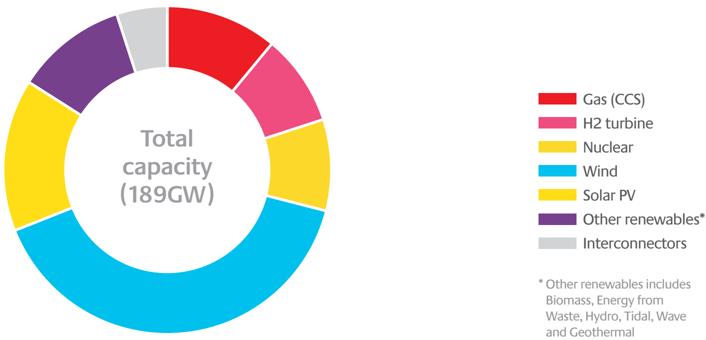
In the 2040s, renewables capacity expands further to meet increased demand from both transport and space heat electrification. This means an increased need for hydrogen peaking capacity (with hydrogen produced mostly from biomass and coal with CCS).

The momentum behind renewables means there is less investor confidence and popular support for nuclear and CCS. Replacement nuclear plants totalling 16GW are gradually approved and constructed, but the rapid build up of renewable energy capacity means that there is less pressure to agree new sites.

With CCS, limited co-ordination and planning leads to delays in follow-on projects in the 2020s, and the growth of renewables capacity creates uncertainty around the appropriate scale of CCS pipelines and stores. In the 2030s, unabated gas power plants begin to be replaced by gas with CCS, however full-scale deployment only occurs by the 2040s.

“ RENEWABLES GROW TO ACCOUNT FOR THE MAJORITY OF ELECTRICITY GENERATION ”

2050 Electricity capacity



* Other renewables includes Biomass, Energy from Waste, Hydro, Tidal, Wave and Geothermal

PATCHWORK
POWER SECTOR IMPLICATIONS

Issues and Implications

- » The intermittency of renewables implies significant backup capacity is required. Where this is provided by hydrogen turbines, geological storage facilities are needed to house the large volume of hydrogen gas needed during periods of intermittent supply and/or peak demand
- » Given the lower load factor and shorter life of wind turbines relative to nuclear power plants, this scenario requires unprecedented build rates to keep up with increasing capacity requirements. Build rates across the power sector average 4GW/yr to 2030 then 7.5GW/yr to 2050. Supply chains need to be built up accordingly
- » This scenario optimistically assumes the lowest plausible cost profile for solar. Further effort is required to drive down the cost of solar and other renewables, as well as storage and low carbon backup technologies, which all play a prominent role in Patchwork
- » Robust market mechanisms (both supply and demand side) or regulation must be introduced to allow a quick response to renewables fluctuations, for example:
  - – Real-time pricing can ensure backup and storage generators are sufficiently rewarded
  - – Smart grid deployment can encourage active participation from households
- » With ~75GW of wind capacity, there will be many hours of the year when electricity supply greatly exceeds demand. Some of this excess supply could be exported if there is sufficient demand elsewhere, subject to interconnector capacity. Electrolysis could be deployed to convert excess electricity into hydrogen. The alternative would be to curtail the excess electricity produced during such periods
- » The high level of offshore wind capacity would also require significant grid reinforcement to allow transmission of power to centres of demand

~75GW

With ~75GW of wind capacity, there will be many hours of the year when electricity supply greatly exceeds demand. Some of this excess supply could be exported if there is sufficient demand elsewhere

PATCHWORK
HEAT SECTOR

In Patchwork, growth in heat demand is eventually curtailed through the extensive roll out of whole-house retrofits selectively targeting key sectors of the housing stock. This coincides with a trend towards urbanisation that means new homes are mostly in the form of energy efficient apartments.

An immediate focus on oil boiler substitution results in an increase in heat pumps.

In some communities there is grassroots support for district heating projects. This is coupled with private sector and regional government investment. Some regions introduce combined heat and power, or seek to utilise local heat sources such as geothermal or marine heat pumps. In the 2030s, these local networks slowly expand and merge to take advantage of scale.

Heat pumps underpin the transition and are adopted early on by 'pioneers' willing to pay a premium for low carbon technologies. Heat pumps grow steadily to supply the majority (60%) of demand by 2050.

In areas where district heating networks are less developed, many homes with heat pumps continue to use gas boilers as a back-up supply. In other locations the local gas distribution grid is decommissioned entirely. As a result, electric heating becomes increasingly important as a source of back-up supply by 2050.

Increases in indoor temperatures continue for a time before breaking from their historical trend to level out by 2030 at 19.5°C. For some, this is achieved through more active heat management in response to environmental concerns, but for others this is simply due to higher costs.

60%

Heat pumps underpin the transition and prove popular early on amongst 'pioneers' willing to pay a premium for low carbon technologies. Heat pumps grow steadily to supply the majority (60%) of demand by 2050

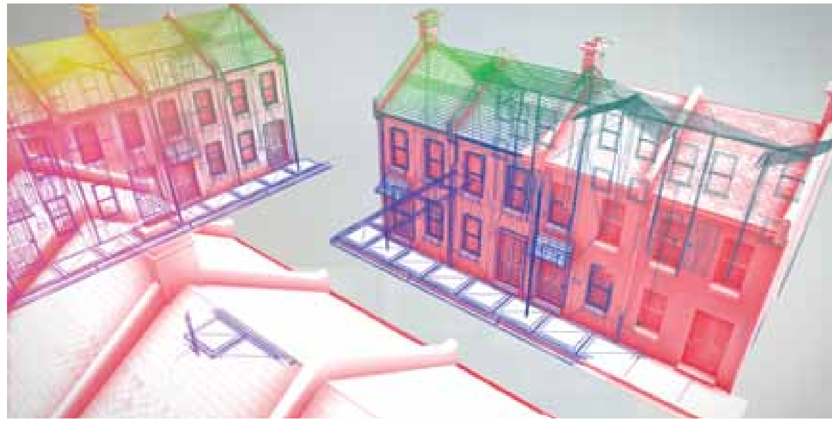
> "IN SOME LOCATIONS THE LOCAL GAS DISTRIBUTION GRID IS DECOMMISSIONED ENTIRELY. ELECTRIC HEATING BECOMES INCREASINGLY IMPORTANT AS A SOURCE OF BACK-UP SUPPLY BY 2050"

PATCHWORK
HEAT SECTOR IMPLICATIONS

Issues and Implications

- A significant challenge must be overcome to improve the performance and usability of heat pumps in the UK to make them desirable to consumers
- The installation of heat pumps requires an upfront investment that is likely to be born by individual households
- Electric heating for back up is much less efficient than a heat pump and the design challenges of home energy management systems must be resolved to avoid overall higher bills for consumers
- The levelling out of indoor temperatures may well result from fuel poverty in some parts of the population, as much as from voluntary sustainable behaviour change in other parts. Such an outcome would have important implications for the comfort and health of those affected
- Engagement is needed to encourage consumers (and landlords) to support adoption of low carbon heat technologies
- Subsidies and/or support schemes are likely to be required by poorer households to help them decarbonise
- Supply chains, knowledge and awareness must be developed in the construction trade to encourage the uptake of low carbon technologies and to ensure effective installation and maintenance
- Support for whole-house retrofits and heat storage will be needed in tandem with heat pumps

> "A SIGNIFICANT CHALLENGE MUST BE OVERCOME TO IMPROVE THE PERFORMANCE AND USABILITY OF HEAT PUMPS IN THE UK TO MAKE THEM DESIRABLE TO CONSUMERS"



PATCHWORK
TRANSPORT SECTOR

In Patchwork, a more metropolitan society pays increasing attention to urban environmental issues, such as local air pollution and noise. Active consumer preference and a supportive policy environment helps to drive the uptake of low emission vehicles. In urban areas, behavioural change and further investment in public transport encourages a shift from car ownership to light rail and bus use. This leads to much slower growth in the number of new cars compared to historical trends, with no further growth in the market for larger cars in particular.

In the near term, the demand for more low emission cars is met through hybrid and plug-in hybrid electric vehicles (PHEVs). Over time, a more favourable policy environment allows for the implementation of tighter emission standards. This is a virtuous circle of growth, with initial consumer demand encouraging innovation, which in turn further stimulates demand by expanding choice and reducing cost. A strong role for communities leads to the introduction of new ownership structures such as car-sharing which helps to accelerate fleet turnover.

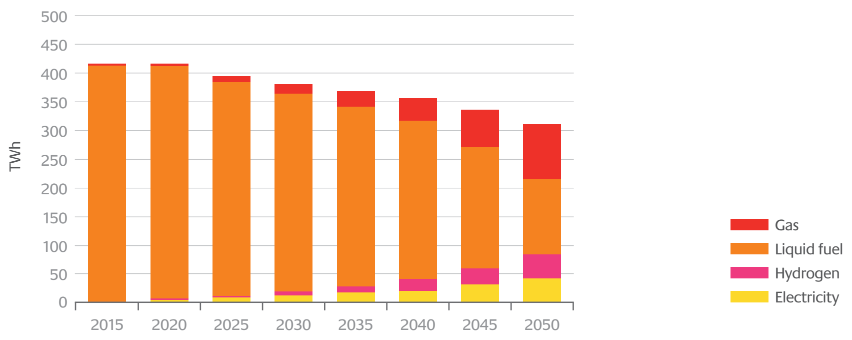
As regional governments lead by example and private firms pursue enhanced brand value associated with sustainable operations, some organisations begin to develop pockets of infrastructure to support hydrogen fuel cell vehicles (FCVs). This is initially limited to back-to-base fleets, but fuel stations are eventually deployed in major population centres and motorways which enables long-distance travel and facilitates the rapid uptake of FCVs by households in the 2040s. This period also sees a decline of the petroleum-based network as demand drops away.

Light goods vehicles (LGVs) move first towards PHEVs and to a limited extent battery electric vehicles (BEVs), as regulatory action on air quality increases their financial attractiveness and improvements in battery technology extends their driving range. Hydrogen fuel-cell LGVs are also rolled out by many private firms as part of their fleet-wide transition.

With HGVs, hybrids take over from conventional internal combustion engines as the dominant vehicle product type by 2030. Around the same time gas-fuelled hybrids begin to pick up, accounting for the majority of the fleet by 2050.

Road Transport Fuel Consumption

Plug-in hybrid electric vehicles lead to a decline in liquid fuel consumption. From 2030 hydrogen fuel cell vehicles pick up market share, accelerating this decline. Natural gas hybrids lead a similar transition in heavy duty vehicles. By 2050, liquid fuel consumption falls to a third of today's levels.



PATCHWORK
TRANSPORT SECTOR IMPLICATIONS

Issues and Implications

» A series of electricity network upgrades and hydrogen infrastructure installations are required in Patchwork, in addition to existing liquid refuelling stations. Operating multiple infrastructures for different vehicle types is likely to be very expensive. It also makes achieving UK-wide coverage difficult

» As overall demand for petrol/diesel falls, refuelling stations (particularly in rural areas) will require financial support to ensure liquid fuel vehicles continue to be catered for

» The least affluent in society, who depend on older, higher emitting cars will be most susceptible to tightening emissions standards. Manufacturers will need to promote a greater range of alternative vehicles affordable to all sections of society

» A supportive policy environment is needed so that low-carbon technologies can compete on a level playing field with high-carbon technology e.g. through the use of carbon-linked taxes

» Support may be required for investors in order to de-risk a multiple infrastructure situation

» UK-based refineries are likely to shut as petrol/diesel use drops away, but imports of refined fuels will still be required e.g. aviation fuels

“UK-BASED REFINERIES ARE LIKELY TO SHUT AS PETROL/DIESEL USE DROPS AWAY, BUT IMPORTS OF REFINED FUELS WILL STILL BE REQUIRED E.G. AVIATION FUELS”

PATCHWORK

INDUSTRY SECTOR

In Patchwork overall industrial activity declines as stricter environmental standards together with a more urbanised population create a shift towards high value design and manufacturing, and knowledge-based activities.

A failure to develop a CCS transport and storage network in time also contributes to the decline, as does the limited availability of biomass. Declining industrial activity is particularly acute in heavy industry (e.g. steel-making) and refining (driven by the shift away from liquid fuel for transportation).

Regional economic specialisation means that industry may still grow in some regions where there is either competitive advantage (e.g. favourably located with energy infrastructure), or an existing cluster of industrial heritage such as the North East of England.

While UK emissions from industry are lower from a territorial perspective, by offshoring industrial activity (especially to countries with less stringent regulations) this actually increases exposure to the higher emissions embedded in imports.

SECTION FOUR

OBSERVATIONS

4

HEATING HOMES

Heating our homes

In high density urban areas, district heating is likely to provide the most cost effective option, while in rural areas heat pumps will be required. A large proportion of the UK housing stock sits somewhere in between these two extremes. The exact proportion of households adopting each solution will be influenced by a number of factors including political support and leadership, consumer preference, technological innovation and cost.

In our scenarios, these factors play out differently. In Clockwork an institutional mandate drives the roll out of district heating super-networks, while in Patchwork, consumer adoption of heat pumps presses ahead as bespoke heat networks prove more difficult to link up.

Insights

The ETI's Smart Systems and Heat programme has summarised key insights around decarbonisation of the building sector:

- Consumers and their priorities (health, comfort, harmony) need to be at the centre of any proposals. Few people care enough about emissions to change how they heat their homes for that reason alone. Solutions that don't meet their needs will be resented. Therefore compelling consumer propositions and business models are needed. Social benefits will also be important.
- System designs and local spatial plans are required for the efficient development of energy assets and to package known but underdeveloped technologies into integrated solutions.
- Integrating the delivery of an energy system transition strategy into local planning processes (with local ownership) will be key to delivering near zero emissions
- Suppliers need support to design, install and set up systems that work well for current and future occupants.

Speed of district heating roll out in Clockwork

Homes with district heating (approximate)			
	Added daily	Added annually	Cumulative
2020	200	70,000	500,000
2030	300	100,000	1,400,000
2040	800	300,000	4,300,000
2050	1,900	700,000	9,300,000

HEATING HOMES THE OPTIONS

Heat Networks

A district heat network involves connecting households in a local area to a central heat source via a hot water pipeline. Within each household, a heat exchange unit extracts the heat from the central pipeline into an internal hot water system. Heat networks offer strategic flexibility by allowing interchangeable sources of heat with minimal disruption to households.

Currently, heat networks account for a very small share of the UK heat market, around 1-2% compared with e.g. 60% in Denmark. New and expanded heat networks therefore have enormous potential to support areas of high population density but there are still many uncertainties regarding the pathway that might be followed. In Patchwork we explore a world where a number of small networks spring up early on, many of them operated by local communities. The difficulties of scaling up and joining up such bespoke schemes means large scale networks are slower to develop.

In Clockwork, heat networks are championed at a national level and rolled out at scale in a more coordinated manner. The emergence of super-networks is supported by the provision of waste heat from a new generation of low carbon thermal power plants, supplemented by large marine heat pumps and geothermal plants.

Heat Pumps

For households in less built-up areas, heat pumps can form the basis of a low carbon heating system in the home, as part of a wider retrofit package. Our analysis suggests that the optimal package could include improvements to walls with external or internal insulation, loft insulation, floor edges, improved airtightness, as well as heat storage and peak backup to support the heat pump. The operation of the heat pump, backup and storage will be controlled by a Home Energy Management System (HEMS).

Heat storage is critical to ensuring any cost effective solution. Heat pumps work best when running evenly throughout the day and night, with any excess heat being stored for use during times of peak demand. Backup is also necessary, as it is prohibitively expensive to install a heat pump capable of meeting the maximum potential heat requirement of a home (which may only be required for a short period every year). Instead, households are likely to maintain a gas boiler or electric resistive radiators for use in such events.

In the case of an electric backup, the distribution grid would require further reinforcement for such occasional events. For gas backup, the gas distribution grid would similarly need to be maintained even though the flow of gas would be reduced to near zero in "normal" weather conditions. Alternatively, gas could be distributed via cylinders instead of pipes, with the distribution grid being retired in due course.

All three approaches are achievable, but the consumer, regulatory and business cases will be a challenge. It is vital that the UK begins to plan effectively over the next decade to avoid embarking on a heat transition that it cannot complete.

1-2%

Currently, heat networks account for a very small share of the UK heat market, around 1-2% compared with e.g. 60% in Denmark. New and expanded heat networks therefore have enormous potential to support areas of high population density but there are still many uncertainties regarding the pathway that might be followed.

MOVING AROUND

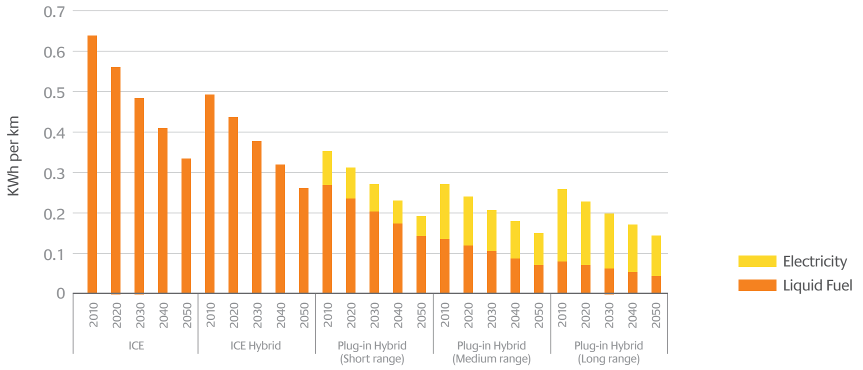
Moving around

Previous research by the ETI (see download) has shown that with sufficient headroom created by negative emissions elsewhere in the energy system, the vehicle fleet out to 2050 can continue to rely to some degree on liquid fossil fuel. Without these negative emissions, the transition towards a more fully decarbonised vehicle fleet would require significantly higher cost and would result in large scale disruption.

Download
An affordable transition to sustainable and secure energy for light vehicles in the UK
www.eti.co.uk/wp-content/uploads/2014/03/2920-ETI-Transport-FULL-Report.pdf

Relative fuel efficiency of liquid fuel vehicles

The chart shows the consumption of liquid fuel and electricity (per km) for selected vehicles used in ESME. Even today's ICE vehicles become more fuel efficient over time, but combined with a shift in the vehicle fleet towards those technologies on the right, aggregate fuel consumption falls dramatically.



A Plug-in pathway

Even in a more limited transition the purchase of conventional internal combustion engine vehicles would be expected to fall away by 2050 as drivers migrate towards more efficient hybrid and plug-in hybrid cars.

Our research has revealed that up to a quarter of new and nearly-new car buyers are willing to pay a premium for plug-in hybrids that perform as well as their conventional ICE counterparts. These consumers would help to kick-start the market for plug-ins, with each new purchase accompanied by a home charging point. Although the electric-driving range of these plug-ins may be modest at first, it will be sufficient for short journeys (constituting over 40% of miles driven).

“ THE REDUCED CONSUMPTION OF LIQUID FUEL WILL HAVE IMPLICATIONS FOR THE EXISTING NETWORK OF REFUELLING STATIONS, MANY OF WHICH ARE ALREADY DEPENDENT ON SOME FORM OF SUPPORT, PARTICULARLY IN RURAL AREAS ”

As plug-in vehicle costs come down (and the carbon price goes up), more consumers will be incentivised to make the change. Moreover, as battery costs in particular come down, consumers would shift towards models with a longer electric range, ensuring less and less liquid fuel consumption over time.

Retaining the option of a liquid fuel mode for longer journeys would ease the pressure to deploy expensive rapid recharging points (and the necessary reinforcement of the distribution grid). Modestly rated recharging points at people's homes and workplaces would be sufficient to meet their needs.

The reduced consumption of liquid fuel will have implications for the existing network of refuelling stations, many of which are already dependent on some form of support, particularly in rural areas.

A Hydrogen pathway

Where less headroom is created by negative emissions, the transport sector will have to be more comprehensively decarbonised. Biofuel can make a contribution, but it still requires adaptation to vehicle technology. The bio-resource itself may be limited in such a scenario amid competition for other end-uses which enable carbon capture. Pure electric vehicles offer a solution for short journeys but they are unlikely to provide the range necessary for longer journeys, necessitating a network of expensive rapid-recharging points.

This leaves hydrogen vehicles as the only remaining viable option. Given the relative immaturity of H2 vehicles compared with plug-ins, any roll out can be expected to lag around a decade behind that of plug-ins. As such, even if a hydrogen fleet is the desired end-point, the delay associated with making this a reality would result in significantly higher interim emissions from the transport sector unless other measures were taken. At the very least, this is likely to mean a rapid move to hybrid vehicles, if not plug-in hybrids as a stop gap.

The pathway towards a full hydrogen fleet would be costly in terms of infrastructure. A slow turnover of the vehicle stock would require liquid fuelling stations to be retained for perhaps 20 years after the sale of new liquid fuel vehicles has dropped away. Any contribution from plug-in hybrids during the interim period would also imply the installation of recharging points (and distribution grid reinforcement) that may or may not have a life beyond liquid fuel hybrids. This depends on whether hydrogen vehicles also include a plug-in electric option. As an alternative, some form of support may speed the turnover, and may be required in order to help poorer households caught between higher liquid fuel costs and the prospects of a new (premium-priced) hydrogen car.

NEGATIVE EMISSIONS

Across different parts of the energy system, the measures available for reducing emissions can vary in cost considerably. If each sector was uniformly required to target the same level of emissions reductions this would imply prohibitively expensive abatement measures. Therefore, the most cost-effective solution may be to go above and beyond in some sectors by targeting zero or even 'negative emissions' where decarbonisation is cheaper, meaning less action is required elsewhere.

Negative emissions

Both of our scenarios rely to varying degrees on negative emissions resulting from the combination of biomass with carbon capture and storage. With biomass, carbon is actively removed from the atmosphere and stored in plant matter as it grows. When the biomass is then harvested and converted into energy, the opportunity is taken to capture the emitted carbon, and store it offshore, securely underground. In this way, the biomass/CCS cycle becomes carbon negative, creating headroom in the emissions budget and reducing the need for expensive abatement measures elsewhere.

UK biomass resource

Ongoing research by the ETI is investigating opportunities for the UK biomass sector (typically through the production of short-rotation-coppice willow and miscanthus, but also through forestry and domestic/municipal waste). This work will help us to identify optimal locations for biomass production, and to assess the wider implications of land use change. Associated modelling work is helping us to explore the optimal use of that biomass resource in the energy system, whether it be for heat, power, gas or liquid fuels.

Imports

Although the ETI work is focused on developing the domestic biomass sector, imports already play a role in the UK energy system. To reflect that reality, biomass imports feature in both of these scenarios, however we have used conservative assumptions on the sustainability and availability of this resource.

“ THE BIOMASS/CCS CYCLE IS CARBON NEGATIVE, CREATING HEADROOM IN THE GHG BUDGET AND REDUCING THE NEED FOR EXPENSIVE ABATEMENT MEASURES ELSEWHERE ”

Carbon Capture and Storage (CCS)

We have previously published work outlining a cost-effective path for the development of CCS in the UK (see p13). Our work has identified the most suitable storage sites, and provided an indication of how we might develop the sector to provide maximum value across the whole energy system. This might begin with a series of flagship CCGT power stations before growing to encompass a series of industry hubs. Eventually, as carbon budgets become ever more stringent, combining CCS with biomass to create negative emissions will become increasingly appealing.

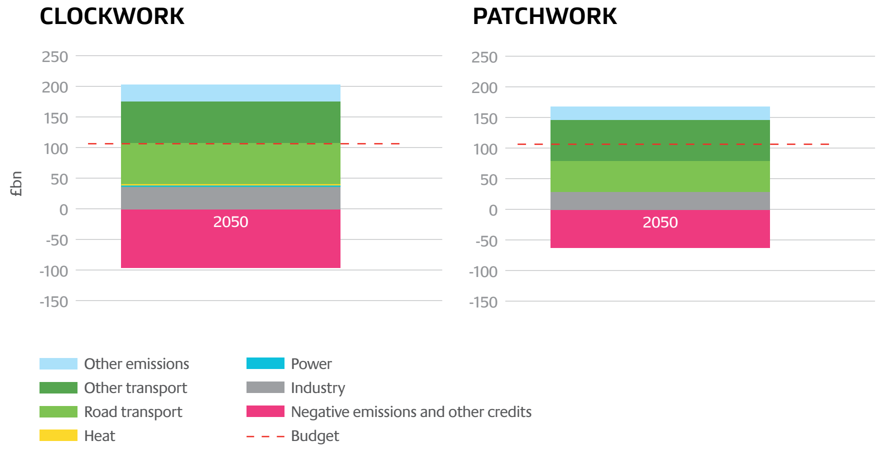
Bio-CCS options

There are several possible avenues for biomass and CCS each offering something distinct to the energy system. Biomass combustion for power is probably the most well understood. This could play a role as a life-extender for existing coal plants through the co-firing of the two resources. Biomass to synthetic natural gas (SNG) is another route, while biomass to liquid biofuel could assist in the decarbonisation of the transport sector. Ultimately though, both of our scenarios come down in favour of hydrogen and power production.

Where hydrogen vehicles make up an important part of the vehicle fleet, the business case for bio-hydrogen is obvious. But in both scenarios hydrogen is an important low carbon fuel in industry and in the power sector too, providing the flexible capacity essential for meeting peak demand and acting as backup for intermittent sources such as wind.

Comparison of Emissions by Sector

Both scenarios have a 2050 net CO_2 budget of 105Mt. By combining biomass and CCS at greater scale, Clockwork benefits from an additional 30Mt of negative emissions compared to Patchwork. The extra headroom in Clockwork helps to avoid more expensive abatement action such as curbing liquid fuel use in transport.



SECTION FIVE

COMPARISON AND COMMENTARY

5

COMPARING COSTS

Capital Spend

One way of assessing costs is to take each scenario in turn and compare it against a counterfactual case which has the same energy demands, but with no carbon targets. The difference is known as the abatement cost. This is the additional cost of meeting those energy demands through a low rather than high carbon energy system.

The capital spend shown here (excluding fuel, operating and maintenance costs) gives an indication of where upfront investment would be required in the energy system for each scenario.

The Clockwork investment is smaller, mainly due to the stronger role for negative emissions in that scenario. A greater share of the costs fall within infrastructure projects such as district heating.

In Patchwork, with a lower level of negative emissions, the higher cost of ultra-low carbon vehicles needed to radically cut transport emissions adds substantially to the abatement cost. The significant deployment of renewable capacity early on also contributes to higher costs.

In Patchwork, the levelling off of indoor household temperatures and the slowdown in new vehicle sales helps mitigate some of the higher cost.

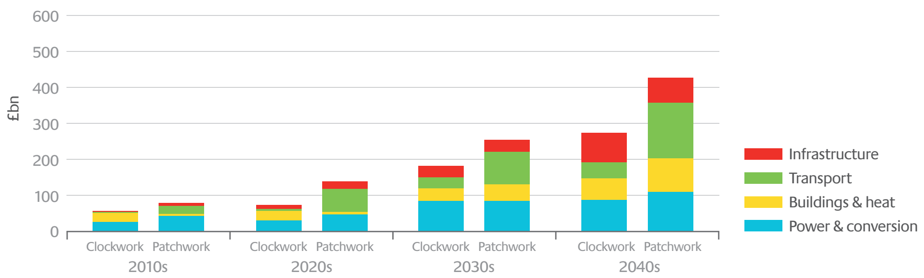
Costs in 2050

In Clockwork, the cost of abatement action taking place in 2050 constitutes around 1.4% of GDP for that year. Patchwork has a marginally higher rate of population growth (with the same GDP per capita growth), which after 35 years delivers a measurably higher GDP. So, while the system cost is higher for Patchwork, the cost as a percentage of GDP is still only 1.6%. These scenarios both fall easily within the range of cases we have explored through our probabilistic modelling, where 2050 abatement costs range from 1-2% of GDP for reasonably optimised systems.

1-2%

These scenarios both fall easily within the range of cases we have explored through our probabilistic modelling, where 2050 abatement costs can range from 1-2% of GDP.

Additional capital expenditure required (per decade) to meet targets



COMMENTARY

Affordability

In both of the stories, the additional cost to society of meeting the challenge of climate change is acceptable (~1.5% of GDP in 2050). In Clockwork there is a greater contribution from lower costs through effective planning and decision making. In Patchwork there is a greater contribution from higher GDP and modestly lower levels of heating, travel and industry. With such a big change from the present there are significant social and political challenges but they are different between the two stories. Higher average disposable income in both scenarios produces different patterns of consumption in each of them.

In many ways, consumer demands in Patchwork look like today, with greater social acceptance of the need to manage resources effectively, including energy. Higher consumer taxes are therefore accepted as a means to put pressure on those who are resistant to these social pressures. The only exception is increased air travel, both for personal and business reasons.

In Clockwork, there is less need for reduced demand to achieve energy targets affordably and the impact of greater government leadership compensates for the lack of a sense of personal responsibility. The differences from Patchwork are not dramatic but real enough to make an economic difference.

~1.5%

In both of the stories, the additional cost to society of meeting the challenge of climate change is acceptable (~1.5% of GDP in 2050). In Clockwork there is a greater contribution from lower costs through effective planning and decision making. In Patchwork there is a greater contribution from higher GDP and modestly lower levels of heating, travel and industry.

COMMENTARY

CONTINUED »

Energy system design

The construction of the energy system is somewhat different between the two scenarios. Although total electricity generation is about the same in both stories, Patchwork has much higher levels of nominal capacity. This is due to the lower capacity factors of renewable sources. Balancing supply and demand of electricity is different in the two stories; the higher levels of variable supply in Patchwork require much higher levels of load-following hydrogen turbines (but with lower utilisation).

Both scenarios have high levels of energy storage, with heat storage dominating in both. We would expect that natural gas storage will continue to have value and that hydrogen storage will also be important, probably at even higher levels than ESME estimates. We should note that ESME has not been designed to estimate the appropriate level of strategic or emergency reserve for the nation.

Although the variations in supply and demand are greater in Patchwork than Clockwork – due to the higher levels of renewables and greater electrification of heating – the same structural approach enables these to be managed. Although we suspect that there would in fact be electrolysis capacity in Patchwork to turn excess electricity into valuable hydrogen (which can then be stored), ESME does not model the fluctuations of supply and demand in enough detail to identify the value of this.

The ETI believes that effective choices of storage technologies, especially heat, hydrogen and natural gas, can accommodate high levels of renewables cost-effectively and also mitigate large swings in demand for electricity. Of course this requires careful design of the supply mix and capacity markets. Control systems have a key role to play, especially vehicle charging and heating, which must be integrated into home energy management systems. While we understand that badly designed energy systems and markets can have significant additional costs for accommodating high levels of renewables and electrifying heating and transport, this is an avoidable outcome.

Infrastructure

Differences of infrastructure are significant between the two scenarios. We have analysed aspects of the energy infrastructure using more detailed tools than ESME to get a sense of this. There are cities in Patchwork with heat-pumps and major electricity distribution system upgrades in a series of poorly planned surges, where in Clockwork a district heating network will have grown out across a city, starting in some key areas. In Clockwork the spreading out of district heating within urban areas is complemented by a roll out of heat-pumps beginning with off-gas grid locations. In Patchwork the spread of technologies looks more like the clustering we have seen with solar in recent years, driven by specific local factors like word of mouth, effective sales forces and concentration of installer resources.

The CO_2 transport infrastructures are likely to be quite different between the two stories, since they will have evolved at different times each with different levers. Electricity transmission systems will be quite different in Patchwork, given the different location of generation and the much greater peak flows from wind. Distribution systems in Patchwork will need to cope with significant periods in summer when supply exceeds demand in many areas and electricity has to be exported, converted or dumped. In Clockwork, energy centres embedded in district heating have a greater impact on overall system balancing in winter, with a tight coupling between electricity supply and heat demand. The largest difference is the abandonment of partly completed vehicle charging and liquid fuel management systems in Patchwork and their rapid replacement with hydrogen distribution.

In both stories, the transition pathways have been constrained by build rate limits. Over time these build rates increase, as we assume that supply chain capacity and investor confidence increases. However some of the implementation rates are at the upper end of what has been achieved historically, particularly in Patchwork.

“ IN BOTH STORIES, THE TRANSITION PATHWAYS HAVE BEEN CONSTRAINED BY BUILD RATE LIMITS. OVER TIME THESE INCREASE, AS WE ASSUME THAT SUPPLY CHAIN CAPACITY AND INVESTOR CONFIDENCE INCREASES ”

COMMENTARY

CONTINUED »

Conclusion

The ETI does not advocate today a single detailed blueprint for a future energy system. We do not yet have knowledge from the development and real-world scale adoption of most of the technologies discussed. Nuclear is the closest to being a tried and tested low carbon energy supply, but it is some time since we built a nuclear power plant in the UK.

Meanwhile people will make their own choices and those can never be fully understood in advance. Small scale demonstrations of a few thousand alternatively fuelled vehicles and their infrastructure, or changing over heating systems in a few tens of thousands of houses, will provide greater insight into this.

Options, choices, actions

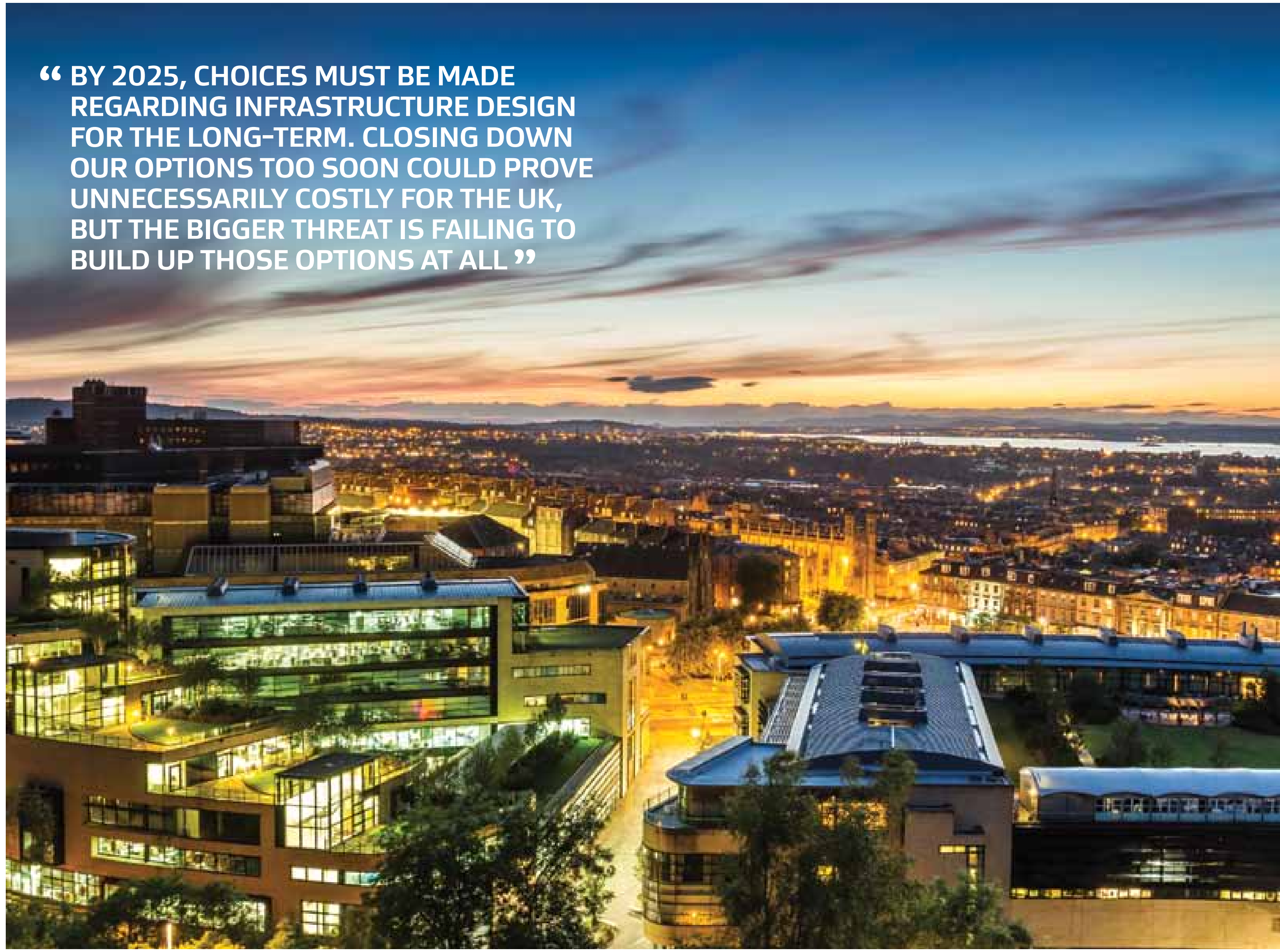
We have approximately a decade to build up a suite of low carbon technology options for the long term. During this time, the ETI recommends that the UK focuses its resources on learning about – and developing the capacity to implement – a basket of the most attractive supply and demand technologies. This includes bioenergy, carbon capture and storage, new nuclear, offshore wind, gaseous systems, efficiency of vehicles and efficiency/heat provision for buildings. Of these, bioenergy and CCS are by far the most critical.

By 2025, choices must be made regarding infrastructure design for the long-term. Closing down our options too soon could prove unnecessarily costly for the UK, but the bigger threat is failing to build up those options at all.

Of course, near term actions are required to meet the carbon budgets, but these have more or less been identified already. When it comes to the longer and more comprehensive transition to 2050, action will be required on another scale altogether. That is why it is so important to get it right, which requires substantial preparation.

In conclusion we would emphasise once more that these are scenarios, not forecasts. Our analysis shows that there are various trajectories possible for reasonably attractive and feasible UK energy systems within a wide range of variation.

Whether people prefer the vision of Clockwork or Patchwork or elements of each, the important thing is that our energy system works to the benefit of all. To that end, we hope these scenarios will stimulate discussion of our analysis and insights so that we continue to learn together.



"BY 2025, CHOICES MUST BE MADE REGARDING INFRASTRUCTURE DESIGN FOR THE LONG-TERM. CLOSING DOWN OUR OPTIONS TOO SOON COULD PROVE UNNECESSARILY COSTLY FOR THE UK, BUT THE BIGGER THREAT IS FAILING TO BUILD UP THOSE OPTIONS AT ALL"

SECTION SIX

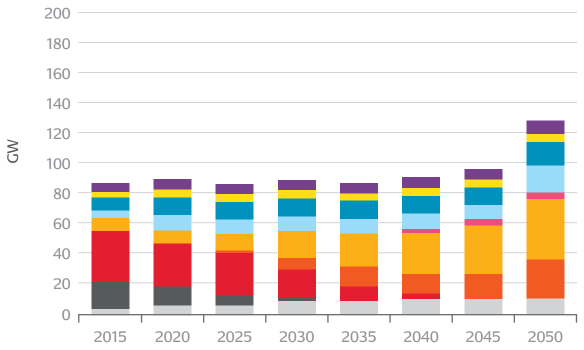
APPENDIX: DATA CHARTS

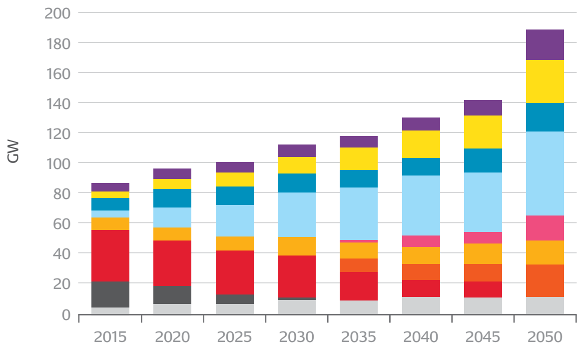
6

ELECTRICITY CAPACITY

Other renewables* | Solar PV | Onshore wind | Offshore wind | H2 turbine | Nuclear | Gas (CCS) | Gas | Coal | Interconnectors

* Other renewables includes Biomass, Energy from Waste, Hydro, Tidal, Wave and Geothermal





CLOCKWORK

- » Nuclear provides 40GW of capacity by 2050
- » Existing pipeline of renewables built out to 2020, then maintained, with some further uptake of wind in 2040s
- » Gas plants retrofitted/replaced with CCS from 2020s
- » Hydrogen takes over from gas for peaking capacity from 2030s
- » Total capacity of ~130GW by 2050. Balance between nuclear, CCS and renewables

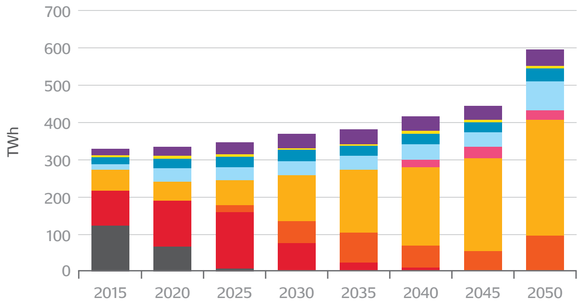
PATCHWORK

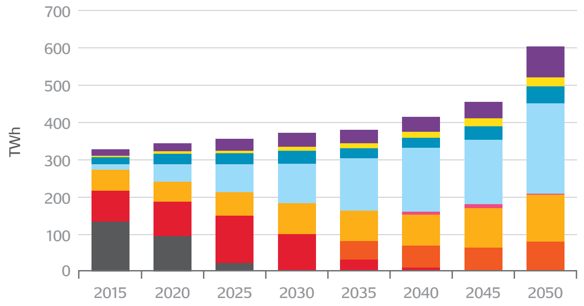
- » Nuclear replacement of existing capacity only (16GW)
- » CCS delayed until 2030s before replacing unabated gas plants
- » Wind power capacity reaches 75GW by 2050, mostly from offshore
- » Significant capacity of hydrogen turbines (17GW) required to balance intermittent supply
- » Solar provides 28GW, Tidal 10GW and Wave 4GW of capacity by 2050
- » Total capacity of ~190GW by 2050, dominated by renewables

ELECTRICITY GENERATION

Other renewables* | Solar PV | Onshore wind | Offshore wind | H2 turbine | Nuclear | Gas (CCS) | Gas | Coal

* Other renewables includes Biomass, Energy from Waste, Hydro, Tidal, Wave and Geothermal





CLOCKWORK

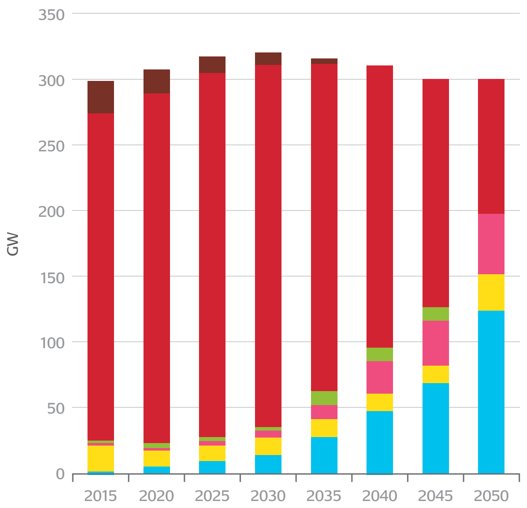
- » Nuclear has the highest load factor of all supply technologies, making the largest contribution to total generation by 2050
- » Gas with CCS has a seasonal role, providing baseload through winter and more backup through summer
- » Improvements to technology means new offshore wind turbines have a load factor of 50% by 2050, meaning a larger share of generation compared to onshore

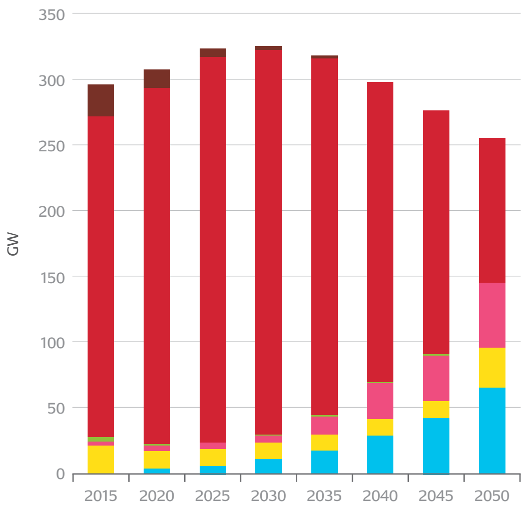
PATCHWORK

- » Despite its limited capacity, the high load factor of nuclear means it contributes ~20% of electricity generation in 2050
- » Of the renewables, offshore wind makes the largest contribution of all technologies, while generation from solar is very modest, given its low load factor of 11% in the UK

SPACE HEAT CAPACITY

Oil Boiler
Gas Boiler
Biomass Boiler
Heat Pump
Electric Heating
District Heating





CLOCKWORK

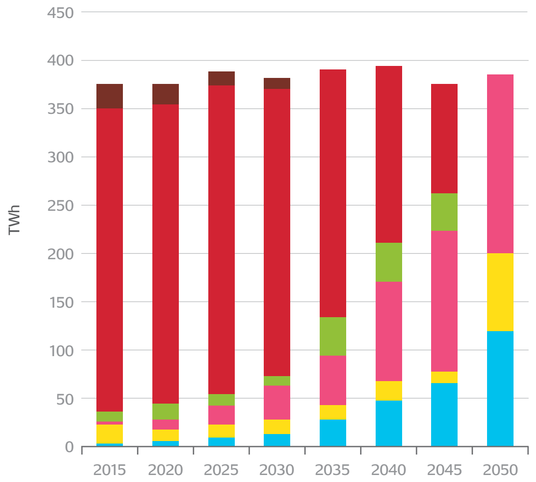
- Thanks to ongoing efficiency improvements in heat supply technologies, and in building fabric, total heat capacity remains fairly constant despite increasing numbers (and temperatures) of homes
- District heating rises steadily to provide >40% of peak capacity
- Biomass boilers play a transitional role, particularly in replacing oil boilers
- The heat pump market steadily grows to provide around 50GW capacity
- Gas boilers remain an important part of the energy system in 2050, but are relegated to back up capacity (in parallel with decreasing coverage of the local gas distribution grid)

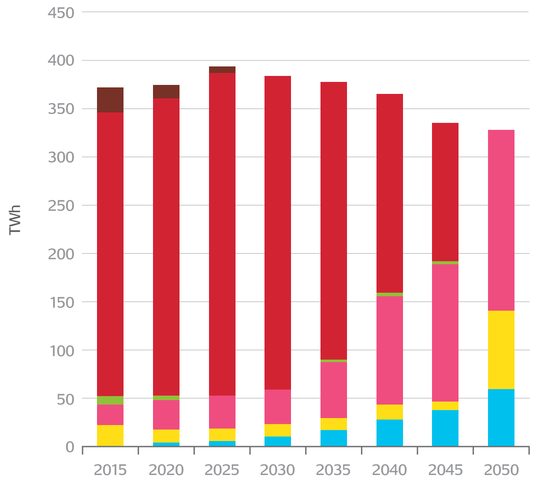
PATCHWORK

- Greater urbanisation and improved building fabric along with technology innovation and changing expectations around indoor temperatures all lead to a reduction in peak heat capacity despite a rising population
- District heating plays a more modest role in patchwork, although still substantially higher than today
- Heat pumps grow to around 50GW of peak capacity by 2050
- The local gas distribution network is decommissioned in some regions, but at a national level, gas boilers remain an important part of the heat capacity mix

SPACE HEAT GENERATION

Oil Boiler
Gas Boiler
Biomass Boiler
Heat Pump
Electric Heating
District Heating





CLOCKWORK

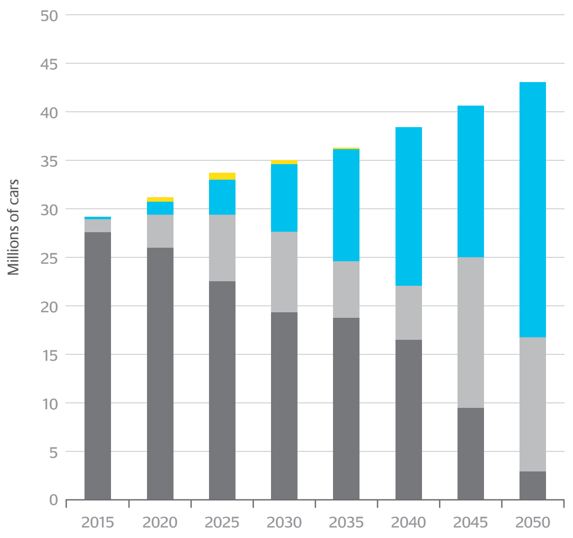
- The operation of the heat supply technologies reveals a more profound transformation than capacity figures would suggest
- With gas relegated to a backup role, the zero carbon technologies dominate heat generation by 2050
- Although heat pump capacity is much lower than district heating, they are run throughout the day (for maximum effectiveness) meaning their contribution to heat supply is much greater

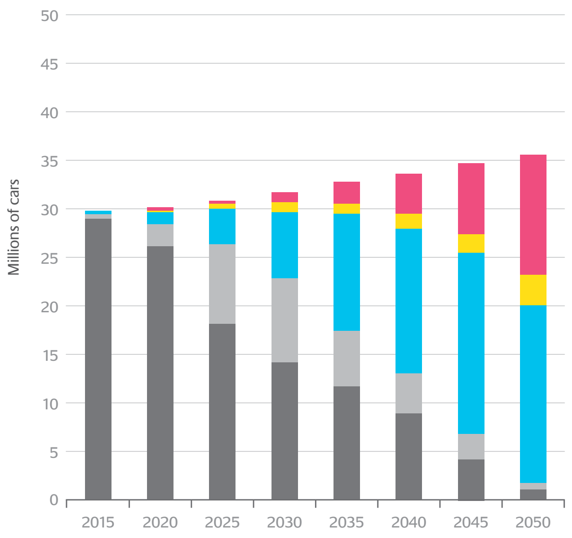
PATCHWORK

- Patchwork experiences a drop in space heat demand from 2025 due to the levelling off of indoor temperatures and the retrofit of selective parts of the housing stock
- With a smaller contribution from district heating, heat pumps provide the majority of heat output by 2050
- Electric resistive heating becomes a significant provider of heat generation, particularly to top up heat supply in households with modestly sized heat pumps

TRANSPORT: CAR FLEET

Hydrogen FCV
Battery EV
Plug-in Hybrid EV
Hybrid ICE
Conventional ICE





CLOCKWORK

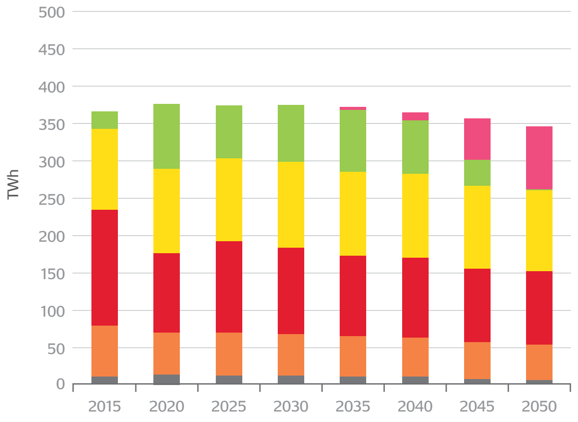
- In Clockwork the car fleet grows to 42m vehicles by 2050
- The continued tightening of vehicle emissions standards drives the uptake of low carbon vehicles from 2020, with conventional ICEs being switched out in favour of hybrids and plug-in hybrids
- Pure electric vehicles make a contribution to these earlier targets but over time consumers choose in favour of the range associated with plug-in hybrids
- The average range of plug-in hybrids increases over time, further encouraging take up until these make up the majority of the car fleet in 2050

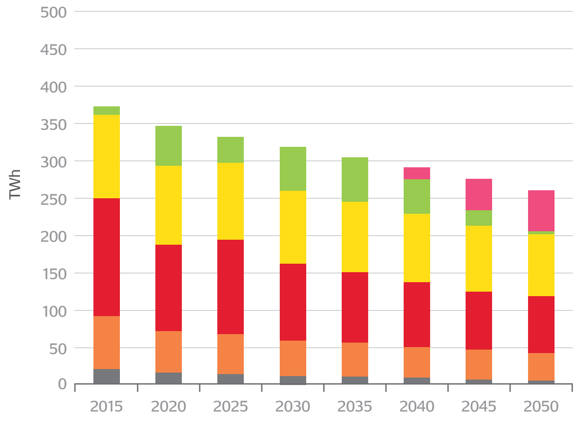
PATCHWORK

- Vehicle demand grows more slowly in Patchwork, rising to 35m cars by 2050
- More progressive vehicle emissions standards from 2020 onwards drive a higher adoption of low carbon vehicles, including hybrid, battery electric, plug-in hybrid and hydrogen fuel cell vehicles
- The need for a more comprehensive decarbonisation of the transport sector leads to a large share of FCVs in the car fleet by 2050 supported by long range plug-in hybrids and some battery electric vehicles

INDUSTRY: CONSUMPTION AND FUEL MIX

Hydrogen
Biomass
Electricity
Gas
Liquid fuel
Coal





CLOCKWORK

- As one of the more expensive sectors to decarbonise, coal, gas and liquid fuel continue to play a role in the industry fuel mix out to 2050
- In the short to medium term, biomass is used to reduce emissions intensity before giving way to hydrogen (also produced from biomass but enabling carbon capture and storage for negative emissions)
- CCS is also used in industry itself, to reduce the impact of carbon intensive fuel use, with approximately 7-8MtCO_2 per year captured from 2030

PATCHWORK

- A shift in economic activity results in less heavy industry and associated fuel use
- Biomass again makes a transitional contribution but resource availability is more limited
- CCS also plays a role but is slightly delayed in this scenario, meaning only 4-5MtCO_2 per year captured from 2035

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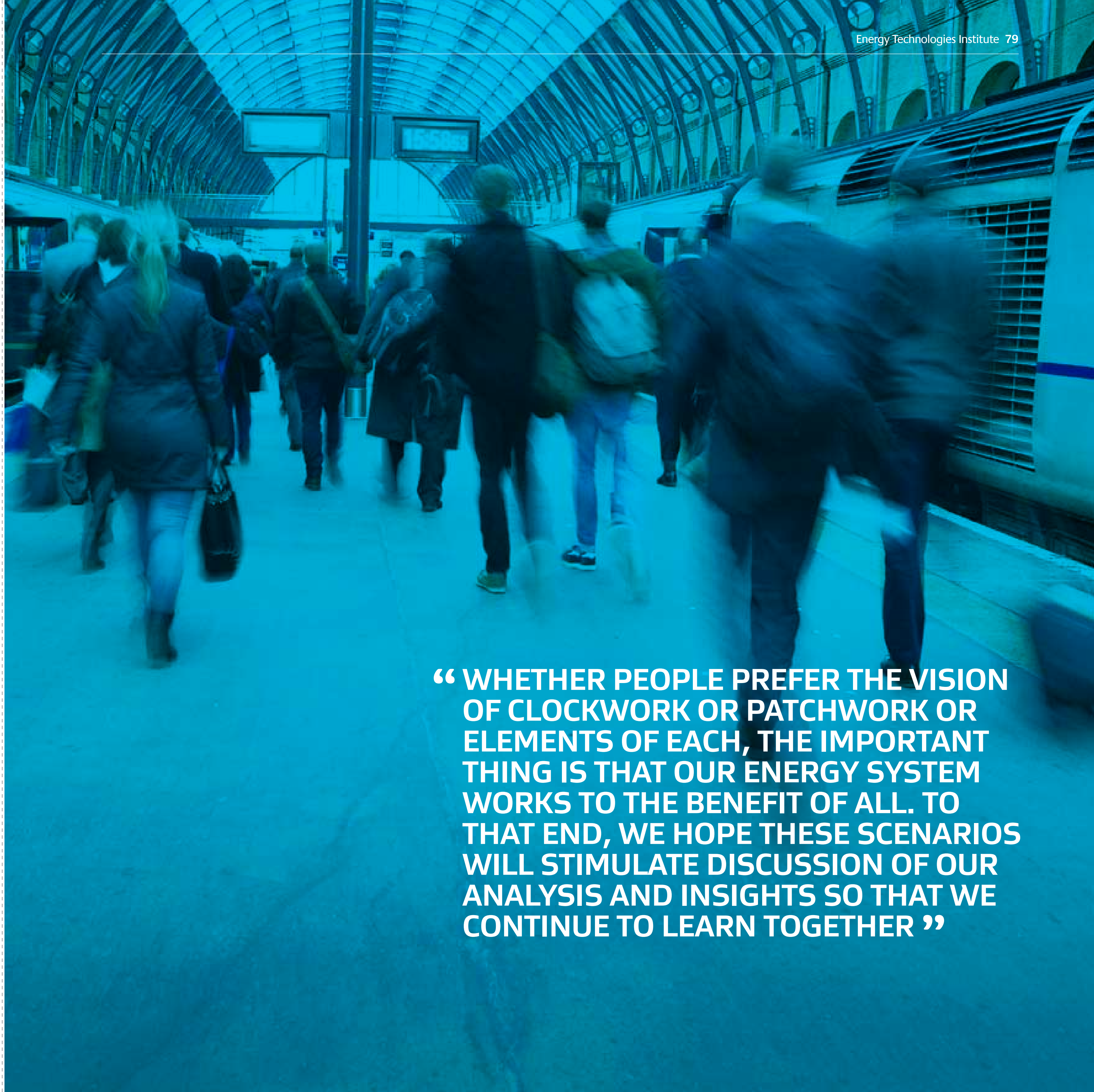

“ WHETHER PEOPLE PREFER THE VISION OF CLOCKWORK OR PATCHWORK OR ELEMENTS OF EACH, THE IMPORTANT THING IS THAT OUR ENERGY SYSTEM WORKS TO THE BENEFIT OF ALL. TO THAT END, WE HOPE THESE SCENARIOS WILL STIMULATE DISCUSSION OF OUR ANALYSIS AND INSIGHTS SO THAT WE CONTINUE TO LEARN TOGETHER ”

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