# National Hydrogen Backbone Study

2025/2026

# Cover note from NESO

NESO is publishing this report to support an informed and evidence-led discussion on the potential role of hydrogen infrastructure in Great Britain's future energy system. As the organisation responsible for strategic whole-system planning, we must ensure that decisions about future network development are grounded in robust analysis, transparent assumptions and a clear understanding of both system-wide opportunities and risks.

The transition to net zero will require significant changes across the energy system, including in how electricity, gas, hydrogen, storage and flexibility interact over time. In that context, questions around the potential role of a national hydrogen backbone are important and timely. They raise broader issues about how different parts of the future energy system might work together, where infrastructure could create system value, and under what conditions investment may be justified.

This report, prepared independently by AFRY, forms part of NESO's wider work to improve the evidence base on long-term strategic energy planning. It brings together analysis of the potential commercial case for a hydrogen backbone with an assessment of wider non-commercial impacts, including resilience, emissions, curtailment, gas reliance and industrial competitiveness. It also explores the sensitivities, tipping points and delivery risks that could materially affect the case over time.

Publishing this analysis does not pre-judge future decisions, nor does it promote any single pathway in isolation. Rather, it is intended to make the evidence more accessible, support informed debate, and help policy makers, regulators, industry and wider stakeholders engage with a complex issue from a shared analytical foundation. The future energy system will need to be resilient, affordable and capable of adapting as technologies develop, demand evolves and policy frameworks mature. That requires us to test different options carefully, understand the conditions in which they create value, and remain open to challenge as new evidence emerges.

Independent analysis and external insight are critical to strengthening strategic decision-making, particularly in areas where uncertainty remains high and choices may have long-term consequences for consumers and the wider system. We see this report as a contribution to that process: a piece of analysis that can inform discussion, be scrutinised constructively, and help refine collective understanding of what a future-proofed energy system may require.

The report's findings are nuanced. It shows that while the base case for a hydrogen backbone may be limited on narrow economic grounds alone, there may be wider whole-system and societal benefits, and the case becomes stronger under certain conditions, particularly where hydrogen demand grows and develops across a broader geography. It also highlights the importance of coordination across policy, regulation, infrastructure planning and market development if such benefits are to be realised.

NESO will continue to work with Government, Ofgem, industry and other stakeholders to ensure that our energy planning reflects the best available evidence and takes account of uncertainty, delivery risk and system-wide impacts. Reports such as this are an important part of that process.

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# Definition of key terms

| Term | Definition |
|---|---|
| Base case | The central modelling case against which sensitivities are compared. |
| BB | Backbone scenario assuming a network of hydrogen pipes is built across Great Britain |
| BID3 | AFRY's proprietary electricity market dispatch model used to simulate and optimise power systems across multiple timeframes and geographies |
| CF | Counterfactual Scenario; a "what if" scenario assuming no hydrogen backbone is built |
| Non-commercial benefits | Wider societal, environmental and system-level benefits of the hydrogen backbone that fall outside the commercial NPV / total system cost comparison, covering emissions, curtailment, resilience, GVA, jobs and industrial competitiveness. |
| Sensitivity / Tipping points | A test showing how results change if a key assumption changes. |

A complete Glossary can be found in the annex

  

# This report presents AFRY's independent assessment of the economic needs case for a national hydrogen backbone in Great Britain (GB)

**CONTEXT — WHY THIS STUDY WAS COMMISSIONED**

- A national hydrogen backbone is a GB-wide network of hydrogen pipelines which could bring important economic, energy security and decarbonisation benefits, but its overall system value has not been independently assessed at a whole-system level.
- To date, most published work has originated from within the gas industry, with few studies providing a holistic view across the electricity and hydrogen systems.
- National Energy System Operator (NESO), in its role as the body responsible for strategic planning of GB's future energy infrastructure, has commissioned AFRY to carry out an independent assessment of the economic needs case.

## Key questions this study answers:

- Under what circumstances is there an economic case for a national hydrogen backbone in GB?
- What are the key factors, assumptions and tipping points that influence that case?

**SCOPE — WHAT THIS REPORT COVERS**

- **Part 1** – Commercial needs case under a well-reasoned Base case, comparing a Counterfactual (no backbone) with a Backbone case using AFRY's BID3 co-optimisation model for the electricity and hydrogen systems (2025–2060). Quantification of non-commercial benefits (emissions, curtailment, resilience, Gross Value Added (GVA), jobs, industrial competitiveness) and
- **Part 2** – Four sensitivities exploring tipping points identified via stakeholder engagement.
- **Extra Sensitivities** –Two further scenarios investigated following completion of the main Part 1 and Part 2 analysis, exploring the role of biomethane as both a complement to hydrogen and a substitute for hydrogen demand.

## NAVIGATION — How to read this report

- **Executive Summary** – consolidated findings across Parts 1, 2 and the Extra Sensitivities including headlines of the study's core findings.
- **Part 1 / Part 2 / Extra Sensitivities** – full methodology, results and analysis.
- **Annexes** – detailed assumptions and supporting evidence for each part.

# Contents



# NESO commissioned AFRY to carry out a study into the needs case for a national hydrogen backbone in GB

## PROJECT OBJECTIVES

1. Part 1: Conduct an independent assessment of the case for a hydrogen backbone in GB, integrating a commercial analysis of its economic benefits with an evaluation of its wider non-commercial benefits.
2. Part 2: Develop a robust understanding of the key tipping points by conducting sensitivity analyses and exploring associated risks, informed by stakeholder engagement.
3. Part 2 analysis extension: Introducing two additional sensitivities to test further key uncertainties and competition from biomethane.

## CONTEXT

- Development of a hydrogen backbone in GB has potential to bring a number of economic benefits
- To date there has been little independent work published providing a holistic assessment of the backbone's benefits
- NESO has therefore commissioned AFRY to carry out an independent assessment of the economic needs case for a national hydrogen backbone.

Stakeholder engagements

Stakeholder engagements

## APPROACH

Part 1

**1 Commercial needs case**

A Base case scenario has been developed using well-reasoned assumptions to represent a plausible GB energy market outlook. It comprises a **"Counterfactual" (CF)** without the hydrogen backbone and a **"Backbone" (BB)** scenario including it. The commercial case was assessed by comparing Net-Present Value (NPV) of the total system costs (CAPEX, fixed, and variable OPEX) across both scenarios from 2025–2060.

**2 Non commercial benefits**

Beyond the commercial outcomes, the analysis compared the Backbone scenario against the Counterfactual in the Base case and sensitivities 1-3 to assess the potential non-commercial benefits to society, including reductions in emissions and curtailment, as well as broader impacts on system resilience and the economy.

Part 2

**3 Key tipping points & exploration of wider risks**

Four sensitivities have been developed to test how key drivers affect the commercial case, focusing on: a reduced and delayed low regrets backbone, hydrogen technology assumptions (e.g. higher electrolyser CAPEX, lower Steam Methane Reforming (SMR) capture rates), non-power hydrogen demand increases with greater regional spread and the role of biomethane as a competing energy vector.

Sensitivities 5 and 6 provide insight into the conditions under which the backbone remains viable when facing higher hydrogen production costs, lower carbon capture rates, and greater substitution by biomethane.

**4 Overall conclusions**

Finally, the results of the study have been synthesised into a short summary answering the following questions, "under what circumstances, is there an economic case for a national hydrogen network and storage system?" and "what are the key factors and sensitivities affecting this economic case?"

1. NPV = net present value; CAPEX = capital expenditure; OPEX = operational expenditure
2. Sensitivities were designed in collaboration with NESO, and engagement with DESNZ and OFGEM



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# Under the Base case, the backbone increases electrolysis and salt cavern deployment while reducing reliance on SMR, electricity transmission and LDES

**KEY FINDINGS**

| | |
|---|---|
| **1** | **Electrolysers:** The development of a hydrogen backbone increases electrolyser deployment across GB, especially in Scotland. Most of the steam methane reforming (SMR) with Carbon Capture & Storage (CCS) capacity deployed in the Counterfactual is removed in the Backbone case because SMR uses relatively expensive gas, and therefore cannot compete with electrolysers in the production of hydrogen |
| **2** | **Hydrogen storage:** The backbone results in greater salt cavern storage than in the Counterfactual, noting that salt cavern storage is located in the north of England due to geological constraints. As such, the backbone allows Scottish green hydrogen to access cost-effective storage solutions with ease. Hydrogen tank capacity shows only very small variations between years. |
| **3** | **Dispatchable generation:** In both Base cases, Combined Cycle Gas Turbine (CCGT) $H_2$ is the most economic low-carbon fully-dispatchable power generator in the long term. Adding a backbone enables a small amount of extra build of CCGT $H_2$ as it will get access to lower priced hydrogen from Scotland. Unabated thermal capacity remains the same between both cases as new build levels have been capped. This cap has been applied to reflect likely investor uncertainty about whether these plants will be allowed to operate long-term, making them less attractive to build. |
| **4** | **Electricity transmission network:** A well-placed backbone allows for a less rapid, and lower capacity build-out of the electricity transmission network. This is because the presence of the backbone means that some of the surplus electricity in oversupplied zones can be converted to hydrogen using electrolysis, and then this hydrogen can be transported to where energy is needed via the backbone. |
| **5** | **Electricity storage:** The backbone results in less Long Duration Electricity Storage (LDES) capacity build. This is because excess generation from renewables will be used to produce hydrogen that can be transported and / or stored, rather than being stored in LDES for long periods. Nationally (6hr duration) battery capacity remains relatively unchanged, with some regional differences reflecting the roll-out of the backbone. |
| **6** | **Renewables & emissions:** The backbone reduces both curtailment of wind generation and national $CO_2$ emissions (noting both scenarios are compliant with government emission targets by design). This is the result of excess renewable generation being utilised in electrolysers to produce hydrogen, combined with less hydrogen production from SMRs. The hydrogen produced is then able to flow across GB to where it is needed, thereby displacing more emissions intensive power generation technologies. |

  

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# The commercial case for a backbone under the Base case scenarios is weak, with little difference in total system costs with or without a backbone

## KEY MESSAGES

**1**

Both cases are closely aligned on:

- Total annual system costs through 2060
- Total undiscounted costs through 2060
- Net present value (NPV).

The Backbone scenario's NPV is marginally lower than that of the Counterfactual scenario, differing by less than 1%.

**2**

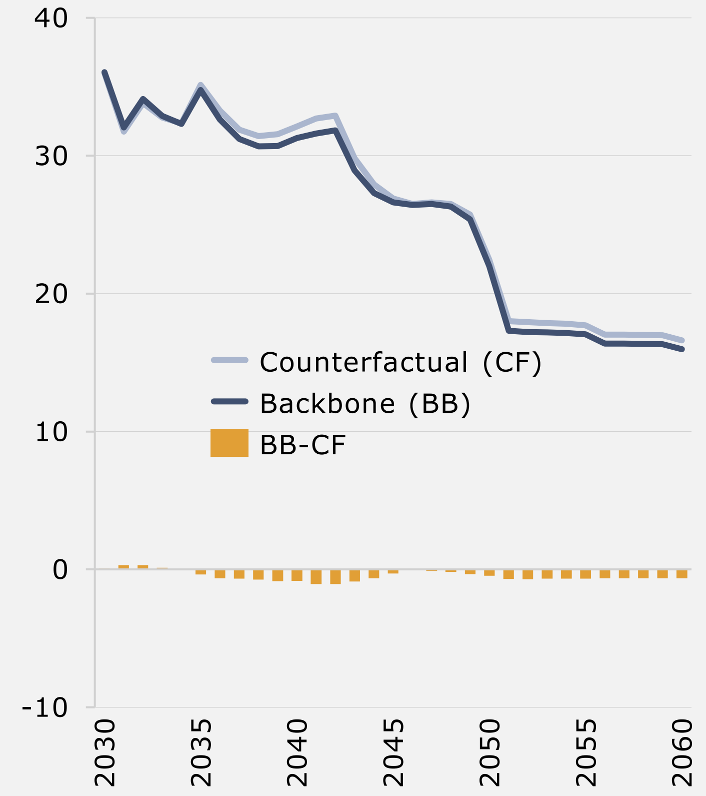
Although the NPV of both scenarios is nearly equivalent, notable differences exist in the contributions of various technologies. Specifically, electrolysers and CCGT Hydrogen play a larger role in the Backbone scenario, whereas SMR CCS and electricity transmission have greater contributions in the Counterfactual scenario.

**3**

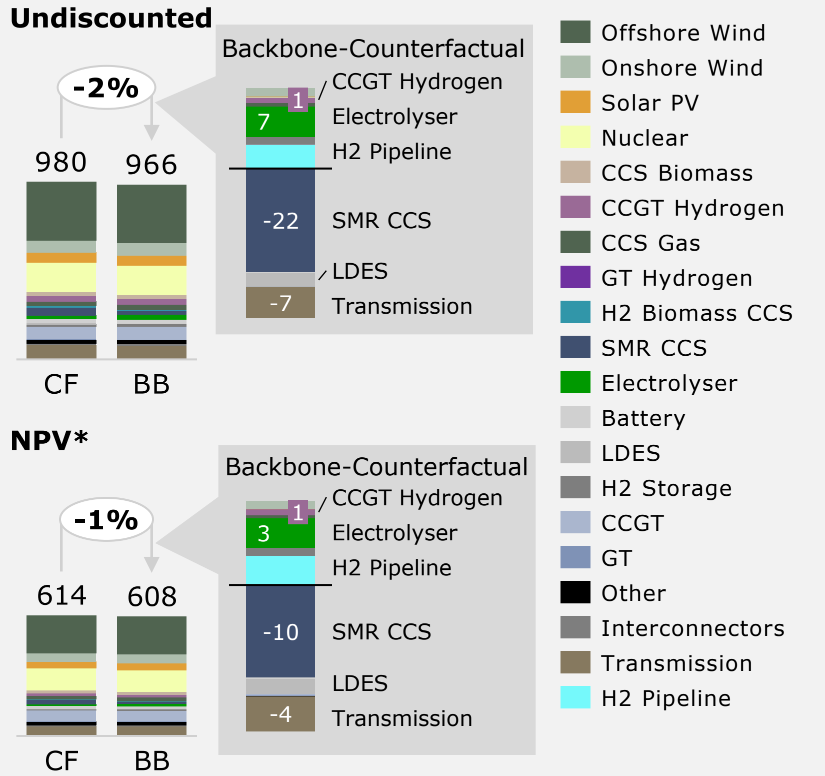
In both scenarios, increased spending occurs primarily in the 2030s, largely due to elevated CAPEX. During the 2040s, CAPEX expenditures decrease, whereas fixed OPEX rises. By the 2050s, CAPEX spending is minimal, and the growth in fixed OPEX also decelerates, leading to a more stable annual system cost.

## SYSTEM COST COMPARISON

ANNUAL SYSTEM COST (BN £, REAL 2023)




TOTAL SYSTEM COST BY TECHNOLOGY (BN £, REAL 2023)




Notes: CF – Counterfactual scenario, BB – Backbone scenario.
* NPV is on a 35-year (2025-2060) period using a rate of 3.5% for the first 30 years and 3% for the last 5 years

# Initially four sensitivities were modelled to identify potential tipping points and highlight impacts of uncertainties

## SENSITIVITIES

1

The capacity of the retained pipelines stays the same as the Base case


### 1. Reduced and delayed hydrogen backbone

- No commissioning of hydrogen pipelines before **2040**, and the national reach of the backbone infrastructure is reduced to Humberside and Merseyside from Scotland.
- Reduced backbone length from **~1700 km to ~900 km**

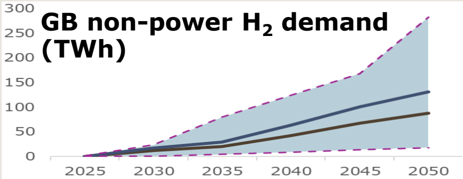
2

| Electrolyser costs | | |
|---|---|---|
| **Avg. 2025-2060** | **Base case** | **Sensitivity** |
| **Capex £/kw** | 248 | 1520 |
| **Opex £/kw/yr** | 42 | 55 |

### 2. Reduced blue $H_2$ production capture rates & higher electrolyser costs

- Reduced carbon capture rates for blue hydrogen production **95% to 85%**
- Increased electrolyser costs to match NESO's 'Levelised Cost of Green Hydrogen' dataset (October 2023)

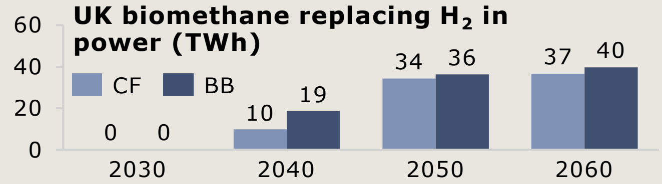
3




### 3. Higher non-power hydrogen demand

- Non-power hydrogen demand rises by **50%** nationally, with broader distribution across zones.
- By 2060 demand rises from **90TWh** (Base case) to **136TWh** (Sensitivity 3)

4




### 4. Biomethane vs Hydrogen

- Biomethane replaces all hydrogen as a fuel in the power sector for both Counterfactual (no backbone) and the Backbone case.
- Biomethane as fuel used in power reaches **~40TWh** by 2060 in the Backbone case

Tipping points: Changes in drivers/assumptions that result in the needs case for a national hydrogen backbone materially changing. Can impact the commercial needs case positively or negatively.

**Modelled in Bid3**
**Backbone iterated**





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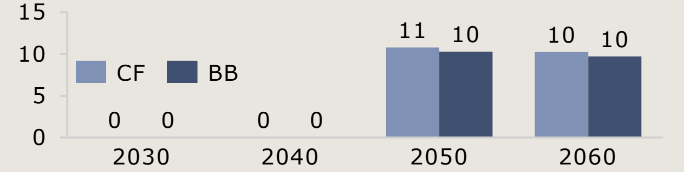
# Two additional sensitivities were conducted to assess the viability of an $H_2$ backbone when biomethane supplies power or non-power industrial demand

## SENSITIVITIES

### 5

| Electrolyser costs | | |
|---|---|---|
| **Avg. 2025-2060** | **Base case** | **Sensitivity** |
| **Capex £/kw** | 248 | 1520 |
| **Opex £/kw/yr** | 42 | 55 |

**UK biomethane fuel use in power as provided by the model (TWh)**

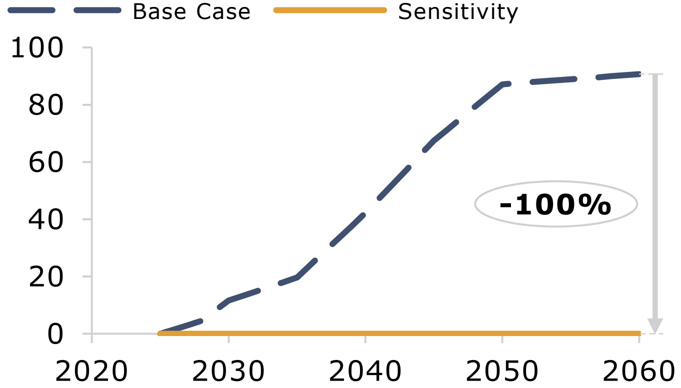



**5. Reduced blue $H_2$ production capture rates & higher electrolyser costs and biomethane introduced in power as an available fuel**

- Reduced carbon capture rates for blue hydrogen production **95% to 85%**
- Increased electrolyser costs to match NESO's 'Levelised Cost of Green Hydrogen' dataset (October 2023)
- Iteration of the backbone to optimise the pipeline capacities based on flows.
- Biomethane is part of the model optimisation. The model is allowed to select biomethane thermal units for build along with CCGT $H_2$ thermal units, both with similar technology costs and technical characteristics including being carbon neutral.
- The biomethane fuel price used–by the biomethane thermal units is the volume-weighted average feedstock price using AFRY's Central feedstock price assumptions and the projected availability of each feedstock type (see Annex.)

### 6

**UK biomethane replacing $H_2$ in non-power (TWh)**




**6. Replacing $H_2$ non-power demand with biomethane**

- Biomethane replaces all hydrogen as a fuel in the non-power sector for both Counterfactual (no backbone) and the Backbone case.
- In contrast to Sensitivity 5, biomethane demand profile is an exogenous input and not part of the model optimisation. The cost in satisfying the demand is exogenously calculated.
- Biomethane as fuel in non-power reaches **~90 TWh** by 2060 in the Backbone case and the Counterfactual.
- Iteration of the backbone to optimise the pipeline capacities based on flows.

Tipping points: Changes in drivers/assumptions that result in the needs case for a national hydrogen backbone materially changing. May impact the commercial needs case positively or negatively.

**Modelled in Bid3**
**Backbone iterated**

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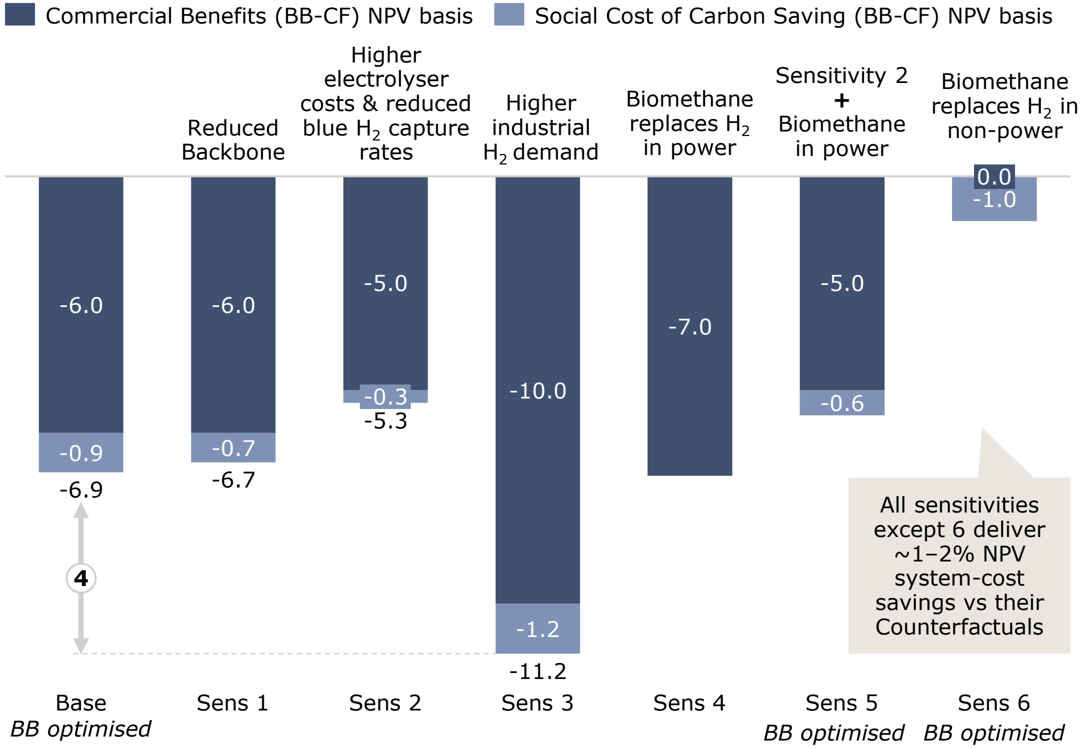
# Across *most* sensitivities, the Backbone consistently delivers system cost savings, with the greatest benefits seen under the higher $H_2$ demand scenario

## TOTAL SYSTEM COSTS BENEFITS (BB-CF) NPV BN £, REAL 2023




***Negative values show savings because of the Backbone***

***BB-CF is with respect to each sensitivity***

Backbone optimisation was only performed for the base case, Sensitivity 5 and 6.
No carbon-intensity value has been assigned to biomethane-fired CCGTs, as biomethane is treated as carbon-neutral.

## WHEN THE BACKBONE DELIVERS THE MOST SYSTEM SAVINGS

- **Backbone savings are primarily driven by reduced SMR-CCS deployment:** The benefits of introducing a backbone mainly stems from the lower reliance on SMR-CCS to meet hydrogen demand as electrolysers are built near high-RES areas to produce and transport hydrogen to areas with high hydrogen demand.
- **High non-power hydrogen demand is the key enabler:** Sensitivities with strong, stable baseload industrial hydrogen demand (especially Sensitivity 3) require significant hydrogen supply, which—without a Backbone—is largely met through locally sited SMR-CCS.
- **The Backbone unlocks large-scale Scottish renewable electrolysis:** By allowing low-cost Scottish wind to supply electrolyser clusters, the Backbone enables these electrolytic volumes to flow south to demand centres, displacing SMR-CCS, reducing curtailment, feeding hydrogen storage and enabling CCGT-$H_2$.
- **Electrolysers in Scotland remain cost-effective even when electrolyser CAPEX is high (Sens 2 & 5):** Electrolytic hydrogen still displaces SMR-CCS even with high electrolyser CAPEX because of abundant, low-cost wind and reduced curtailment.
- **Only when non-power hydrogen demand is removed (Sensitivity 6) do savings fade:** Replacing $H_2$ industrial demand with biomethane removes the fundamental driver of the backbones value, leaving almost no SMR-CCS to displace. The only remaining savings arise from the social cost of carbon via less running of the existing SMR-CCS build as well as lower reliance on gas fired CCGT generation to meet demand.



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**BB vs CF**

- Positive impact
- No material impact
- CF is better



# The backbone increases $CO_2$ savings, cuts curtailment, increases green hydrogen production, and reduces gas reliance which strengthens resilience

| | Type of Non-Commercial Benefit | Definitions of Non-Commercial Benefit | Result Highlights (Backbone vs Counterfactual)[1] | Impact |
|---|---|---|---|---|
| Environmental & Climate | Societal $CO_2$ Cost Savings | – NPV of Societal $CO_2$ Cost Savings (Net of Emissions Trading System (ETS)) | – £920 million (Mn) in savings[2] | Positive impact |
| Environmental & Climate | Risk of Water Stress | – Pressure on water resources from green hydrogen production[3] | 1. <1% of current average GB water supply per year<br>2. May be a material impact in particular regions, needs further analysis (see annex) | 1: No material impact<br>2: CF is better |
| System Integration | Integration of Renewable Electricity | – Impact on RES curtailment | – Total of ~520 TWh of curtailment savings[2]<br>– ~15 TWH per year annual avg.[2] | Positive impact |
| System Integration | Integration of Green & Blue Hydrogen | – Impact on green and blue hydrogen production | – 167 TWh of more $H_2$ production[2]<br>– 82% of total 35-year hydrogen production is green in the BB vs 60% in the CF | Positive impact |
| Security of Supply | Diversification | 1. Proportion of total power demand met by imports<br>2. Total gas reliance in power and hydrogen<br>3. Diversity index of energy sources | 1. 183 TWh of more power imports[2]<br>2. ~ 644 TWh of gas use savings[2]<br>3. No difference between the two scenarios | 1: CF is better<br>2: Positive impact<br>3: No material impact |
| Security of Supply | Resilience | System impacts due to:<br>1. Gas price shock for select year (2055)<br>2. Frequency & magnitude of lost load in low wind weather year | 1. £2.6 bn saving in shock year 2055<br>2. No loss of load in both scenarios in any year | 1: Positive impact<br>2: No material impact |

Note: 1 - All values refer to the Backbone as compared to the Counterfactual. 2 – over the modelled period of 2025-2060 (35 years) 3-does not include water needs for any other hydrogen production process such as SMR or Gasification





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**BB vs CF**

- Positive impact (green)
- No material impact (amber)
- CF is better (red)



# The backbone has limited impact on GVA and jobs compared to the Base case but may boost industrial competitiveness through access to low-cost $H_2$

**Economy, Employment & Skills**

| Type | Definitions | Result Highlights (Backbone vs Counterfactual) | Impact |
|---|---|---|---|
| **Gross Value Added (GVA)** | – Used to measure the contribution of the backbone to the overall economy as a measure of economic output or benefit | – ~£5 bn less GVA (<1% of total GVA)<br>– Regionally, the BB scenario shifts GVA towards Northern Scotland, Midlands, and East Anglia at the expense of regions sandwiched in between | Amber (No material impact) |
| **Employment Impacts** | – Estimates the employment impact (full-time equivalent (FTE) job years) due to domestic GB investment | – ~1,000 fewer full-time equivalent (FTE) job years<br>– ~3,100 FTE job years per year over the 35 years<br>– More FTE job years in England and less in Scotland and Wales | Amber (No material impact) |
| **Industrial Competitiveness** | – Improved industrial competitiveness arising from reduced hydrogen cost to industry | – Hydrogen consumers will save ~ £4 bn (2040-2060) due to lower hydrogen prices increasing competitiveness | Green (Positive impact) |

Note: FTE Job years - “1,000 FTE job years” represents the equivalent of 1,000 full-time jobs sustained for one year - One FTE job year equals one person working full-time for one year (≈2,000 hours). All values refer to the Backbone as compared to the Counterfactual

- ↑ Better than the Base case
- – The same or marginal difference than the Base case
- ↓ Worse than the Base case

# Higher $H_2$ demand leads to the greatest monetised benefits from the backbone

| | NCB | Base case | Sensitivity 1 | Sensitivity 2 | Sensitivity 3 | Overall summary |
|---|---|---|---|---|---|---|
| | | (Backbone vs Counterfactual)[1] | | | | |
| Environmental & Climate | **Societal $CO_2$ Cost Savings** | – ~£1bn in savings[2] | ↓ | ↓↓ | ↑ | **Savings**: Sens2. ~£0.3bn; Sens1. ~£0.7bn; Base ~£1bn; Sens3. ~£1.2bn |
| Environmental & Climate | **Risk of Water Stress[3]** | – May be a material impact in particular regions (S.Wales and N. Scotland), needs further analysis. | ↑ | ↓ | – | Sens.1 removes additional pressure on South Wales. Sens.2 concentrates nearly all additional demand in Scotland—particularly in the North, which is itself currently a water-stressed region. |
| System Integration | **Integration of Renewable Electricity** | – Total of ~520 TWh of curtailment savings[2] | ↓ | ↓↓ | – | Sens.2 has the lowest curtailment savings of 380 TWh given that it has the lowest green hydrogen production. |
| System Integration | **Integration of Green & Blue Hydrogen** | 1. 167 TWh of more $H_2$ production[2] 2. 22% greater green hydrogen production | ↓ | ↓↓ | – | Sens. 3 matches the base case in added $H_2$ but delivers a lower share of green hydrogen. Sens. 2 shows both the lowest green-$H_2$ share and the smallest additional production vs its counterfactual. |
| Security of Supply | **Power imports and gas reliance** | 1. 183 TWh of more power imports[2] 2. ~ 644 TWh of gas use savings[2] | – | ↓ | – | Sens. 3 achieves the greatest gas-use savings from the backbone but also leads to the largest rise in net power imports. Sens. 2 exhibits a similar trade-off, with gas-use savings closer to the Base case. |
| Security of Supply | **Gas Price Shock** | 1. £2.6 bn saving in shock year 2055 | – | ↓↓ | ↓ | Gas-price shock exposure tracks gas reliance: all cases depend more on gas, but Sens. 2 shows the highest absolute reliance under its BB case, making it the most sensitive to a gas-price shock. |

Note: 1 - All values refer to the Backbone as compared to the Counterfactual. 2 – over the modelled period of 2025-2060 (35 years) 3-does not include water needs for any other hydrogen production process such as SMR or Gasification

# The Backbone delivers ~1% savings in the Base Case, equivalent to less than £200m per year over 35 years and just 0.2% of UK GDP

## STUDY HEADLINE DATA AT A GLANCE

**183 TWh** of more power imports

**644 TWh** of gas use savings

**520 TWh** of curtailment savings

**~1%** Base case NPV costs savings

**~£1 bn** total societal $CO_2$ cost savings

**<1% lower** total GVA in the power sector*

**167 TWh** more $H_2$ production - 82% of which is green

No water scarcity risk detected on national level, but may vary regionally

**~£4 bn** cost savings for industrial $H_2$ users**

**<1% lower** in FTE Job years in the power sector*

Base case system cost savings are lost when backbone costs are increased by **~3.5 X**

**Sensitivity 6** total system costs savings **NPV ~1% (-60% vs Base case)**

**Sensitivity 2** total system costs savings **NPV ~1% (-17% vs Base case)**

**Sensitivity 1** total system costs savings **NPV ~1% (0% vs Base case)**

**Sensitivity 5** total system costs savings **NPV ~1% (-20% vs Base case)**

**Sensitivity 3** total system costs savings **(NPV) ~2% (67% vs Base case)**

**Sensitivity 4** total system costs savings **NPV ~1% (17% vs Base case)**

Base case commercial benefit

Non-commercial benefits of the Base case

Sensitivities

**Sensitivities**

1. Delayed & reduced backbone
2. Higher electrolyser costs & lower capture rates for blue hydrogen
3. Higher non-power hydrogen demand – (higher regional spread)
4. Biomethane replacing hydrogen in power
5. Sensitivity 2 + Biomethane in power
6. Biomethane replaces $H_2$ in non-power

Unless otherwise stated:

- All values refer to the Backbone as compared to the Counterfactual
- Backbone = BB, Counterfactual = CF

*The lower GVA and jobs values observed in the Backbone scenario of the Base case is primarily attributable to reduced capital expenditure.**Cost savings over 2040-2060. 2040 is assumed as the point from which a commoditised hydrogen market emerges

# Under Base case assumptions, the backbone lacks a strong economic case but delivers growing benefits under a more ambitious hydrogen future

## STRENGTHS THROUGH WIDER NON-COMMERCIAL BENEFITS

- Non-commercial benefits provide a more complete picture of the system value of a national hydrogen backbone.
- In addition to £6 billion (bn) in system cost savings, the backbone (BB) adds £0.92bn Net Present Value (NPV) in societal carbon cost reductions, bringing total quantified benefits close to ~£7 billion versus the Base case Counterfactual (CF).
- The backbone over 35 years:
  - Cuts curtailment by ~520 TWh (31% reduction versus CF)
  - Boosts hydrogen output by 167 TWh (82% share is green)
  - Reduces gas use by ~644 TWh, improving resilience
  - Could save industrial hydrogen consumers £4 bn (2040–60)

## WEAKNESSES

- Including a backbone delivers only marginal economic benefits for Great Britain's (GB's) electricity and hydrogen systems, with total system cost savings of around 1% (NPV) over 2025–2060 compared to the CF.
- The £6 billion savings in the Base Case attributed to the Backbone equates to less than £200 million annually over 35 years—representing just 0.2% of the UK's GDP in 2024.
- No additional Gross Value Added (GVA) or job growth is observed—impacts are primarily regional redistribution.

## OPPORTUNITIES UNDER THE SENSITIVITIES

- The modelling supports a simpler, low-regrets backbone design excluding southern regions.
- Higher non-power hydrogen demand improves total system cost savings (including social cost of carbon savings) enabled by the backbone beyond other sensitivities, but the overall economic benefit remains limited (~2% compared to the sensitivity CF).
- Even with biomethane fully replacing hydrogen in power, the backbone remains economically justified—suggesting a twin-track approach could be further explored.

## THREATS OF RISKS & BARRIERS

- The backbone is a system-level investment whose value depends on timing, policy alignment, and demand growth – around which there are a number of uncertainties.
- The modelled benefits of the backbone only fully materialise under certain enabling conditions.
- These benefits are highly sensitive to backbone cost assumptions and hydrogen technology costs/performance.
- Risk management in this context is about ensuring the enabling ecosystem (policy, regulation, social licence) moves in sync, including across energy vectors and value chains.

NPV is on a 35-year (2025-2060) period using a rate of 3.5% for the first 30 years and 3% for the last 5 years

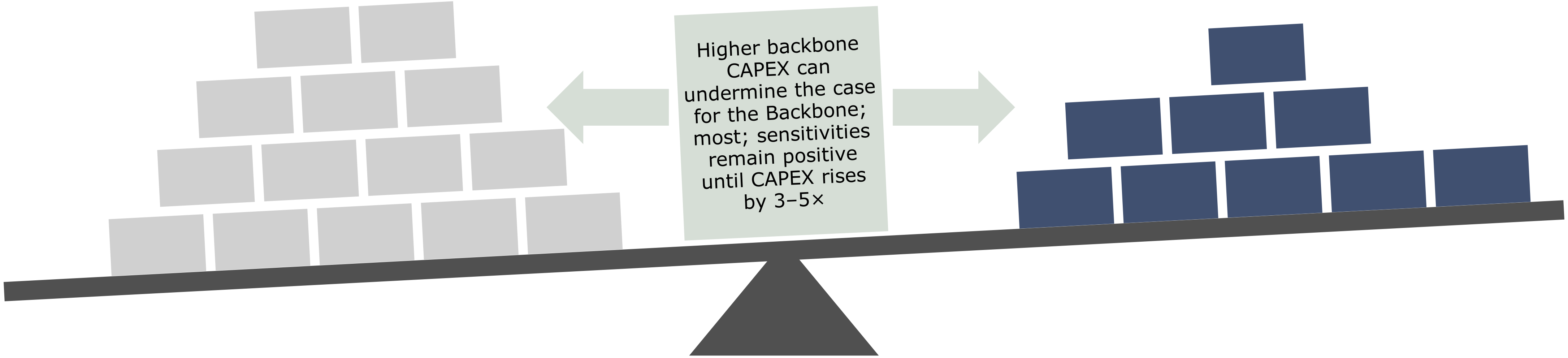
# The backbone's value pivots on non-power $H_2$ demand: strong demand amplifies benefits, zero demand removes them

## HIGHER NON-POWER HYDROGEN DEMAND (SENSITIVITY 3)

- A major uplift in non-power (industrial) hydrogen demand (rising from 90 TWh in the Base case to 136 TWh by 2060) creates the strongest system-wide benefits for the Backbone.
  - The high baseload demand drives substantial utilisation of the network
  - The higher demand enables Scottish electrolysis to displace large volumes of SMR-CCS and reduce transmission and LDES needs. **This is the tipping point where the backbone delivers the greatest benefits.**

## NO NON-POWER HYDROGEN DEMAND (SENSITIVITY 6)

- Removing industrial hydrogen demand and replacing it entirely with biomethane eliminates the conditions under which the backbone adds value.
  - With no baseload hydrogen demand from the industrial sector, the conditions under which SMR-CCS could be displaced by Scottish electrolysers disappears, and thus system costs converge with the Counterfactual.
  - The backbone provides essentially no *commercial* benefit under these conditions but continues to provide wider benefits in terms of the social cost of carbon savings.



# When there is sustained non-power $H_2$ demand a national-scale hydrogen network delivers economic value subject to infrastructure costs

### Core findings

Building a hydrogen ($H_2$) backbone delivers economic benefits for Great Britain's (GB) electricity and $H_2$ systems, with total system cost savings of around 1%-2% (NPV) over 2025–2060 compared to a scenario without it (the "Counterfactual") as long as non-power $H_2$ demand persists.

-

Monetised benefits (including social cost of carbon savings) from a backbone range between £1-£11 billion NPV* across the Base case and all 6 sensitivities.

-

Backbone value is demand-led: across nearly all sensitivities, the backbone delivers benefits, but the commercial benefits it can provide are highly conditional on displacement of SMR-CCS that supplies non-power (industrial).

-

When a backbone exists, Scottish wind + electrolysers can displace local SMR-CCS, reduce curtailment, and supply $H_2$ storage and demand centres.

### Insights from Biomethane Sensitivities

Sensitivities 5 and 6 extend the analysis to consider alternative evolutionary paths for the GB system.

-

Biomethane can potentially be a bridge to and complement $H_2$: in future if higher $H_2$ technology costs and biomethane competition in the power sector arise (as per Sens. 5), the backbone starts to commission later—post-2040, and near-term power needs can be complemented by biomethane-fired CCGTs. Biomethane provides a bridge to conditions that make economical sense for the backbone to be built and provide benefits.

-

If biomethane substitutes for non-power $H_2$ (as per Sens 6), the $H_2$ backbone's value diminishes, indicating industrial $H_2$ demand is the key driver of backbone benefits.

-

Biomethane's ability to substitute $H_2$ demand will be limited by how quickly the availability of biomethane feedstocks and alternative competing uses for biomethane ramp up in the UK over the long term.

### Strategic Implications

Salt caverns and select pipeline segments (Scotland to Northeast England) provide low regret enduring strategic value and optionality across a wide range of future system pathways.

-

Benefits can be eroded by backbone CAPEX increases; corridors that show strong utilisation under a range of scenarios should be prioritised to protect economics.

-

The backbone unlocks scalable green $H_2$ deployment, delivering curtailment reduction, system flexibility, and savings in the social cost of carbon—even when electrolyser costs are high and there is biomethane competition in power.

-

Delaying $H_2$ infrastructure *development* in favour of biomethane in the near term could limit the full benefits of a dual-vector system longer term.

*NPV is on a 35-year (2025-2060) period using a rate of 3.5% for the first 30 years and 3% for the last 5 years

# The strategic risk is treating biomethane as a substitute for early $H_2$ investment, rather than as a complementary buffer while $H_2$ infrastructure scales up

**The Role Biomethane Could Play**

**Biomethane's potential as a bridge or complement**

- Biomethane can temporarily meet part of industrial or power-sector demand while hydrogen production, transport, and storage scale.
- Biomethane can sit alongside hydrogen in a mixed-fuel future, with each serving the roles where it is most effective. However, for a backbone to make sense, there must be strong hydrogen baseload demand from the non-power sector.
- Real-world adoption of biomethane vs hydrogen in industry and power is uncertain and influenced by cost, retrofit, regulation, and supply constraints.

**Cross-Vector Opportunities**

**Some infrastructure choices preserve option value across biomethane- and hydrogen-led futures**

- Salt caverns capable of storing hydrogen or biomethane provide high-value system optionality.
- Hydrogen transport can reduce the need for some electricity network reinforcement, while biomethane leverages existing gas networks with limited retrofit.
- Prioritising assets that serve multiple vectors reduces exposure to fuel-specific forecast uncertainties.

**Sequencing & Timing**

**Sequencing decisions are path-dependent and not reversible at equal cost**

- Heavy early reliance on biomethane risks locking in non-hydrogen pathways.
- This delays hydrogen learning, slows cost reduction, and raises the eventual cost of transition if hydrogen is later required at scale.
- Conversely, limited early hydrogen build-out does not preclude biomethane uptake.

**Least-Regrets Infrastructure Pathways**

**Certain assets remain valuable across almost all biomethane and hydrogen sensitivities**

- Across nearly all sensitivities, the Scotland → Northeast England corridor emerges as the most robust segment of a future backbone.
- Storage (salt caverns) and initial backbone segments provide optionality whether biomethane or hydrogen dominates in the medium term.

# Realising the benefits of a national backbone requires coordinated planning, policy and technology development

## Primary risk buckets

- **Public Acceptability:** Local resistance can delay and/or fragment the backbone, while offtake projects remain stranded or relocated increasing costs.
- **Technological Uncertainty:** Performance, scalability and economics of hydrogen technologies and competing vectors.
- **Demand Uncertainty:** Slower uptake in key sectors may lead to overbuilding and stranded assets.
- **Regulatory & Policy Uncertainty:** Delays in harmonising regulations or mismatched incentives discourage investment.

## Cascading effects

1. **Coordination and timing**: Delays and fragmented planning across decarbonisation pathways create inefficiencies, missed integration opportunities, and higher costs.
2. **Supply–demand alignment:** Uneven hydrogen uptake, sectoral delays, and misaligned policy supporting varying vectors could lead to underutilised or stranded assets including pipeline branches and storage (salt caverns).
3. **Hydrogen bottlenecks:** Limited $CO_2$ transport/storage capacity and permitting could restrict SMR-CCS (blue $H_2$) deployment. Conversely, higher electrolyser costs or delays in large-scale $H_2$ storage bring increased blue $H_2$ use and maintain gas reliance for longer. The combination of these factors could significantly reduce backbone benefits.

## Mitigations

**Mitigation 1**

1 Establish stable and long-term alignment between policy frameworks with clear targets to build investor and industry confidence

**Mitigation 2**

2 Strengthen cross-sector planning, streamline permitting, and focus on stimulating hydrogen demand through clear sector incentives to avoid bottlenecks and accelerate delivery of the ecosystem

**Mitigation 3**

3 Phased modular design of the backbone – Stage investments to allow scaling up or rerouting as demand evolves

**Mitigation 4**

4 Engage communities early through transparent communication and education campaigns to avoid delays and opposition

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# A Base Case was developed to assess the economic benefits of the Backbone

**Development of a well reasoned Base case:** A plausible view of the future GB energy system, comprising a Counterfactual (no backbone) and a Backbone scenario, built on aligned assumptions for demand, technology costs and policy build.

**Commercial assessment of the needs case:** Comparing total system costs between the Counterfactual and Backbone scenarios of the Base case

Non-commercial benefits: Quantification of societal, environmental and economic benefits identified through stakeholder engagements and literature review

**Conclusions:** Assessment of the hydrogen backbone's strategic value from the insights from the Base case finding

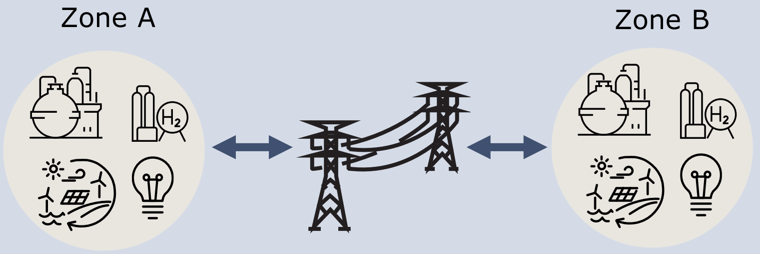
# Contents



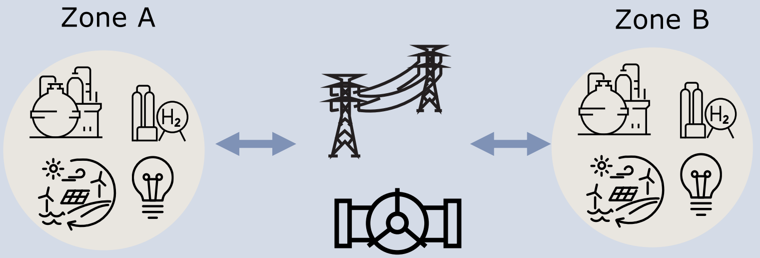
# AFRY has developed a Base case that consists of two scenarios – a "Counterfactual" (without the $H_2$ backbone) and a "Backbone" scenario

## OUR TWO BASE CASE SCENARIOS HAVE BEEN DESIGNED TO SHOW THE IMPACT OF A HYDROGEN BACKBONE

**Counterfactual case:** No centrally developed hydrogen backbone. This results in isolated hydrogen demand clusters, and only very limited contributions by hydrogen to interzonal balancing of the electricity market.




**Backbone case:** A national hydrogen backbone (i.e. a national network of hydrogen pipelines) is developed. This results in well interconnected hydrogen demand clusters, which means that hydrogen can contribute to interzonal balancing of the electricity market.




- The two scenarios were designed to assess the impact of a hydrogen backbone on a well reasoned Base view of how the world may look in future
- To make the two scenarios directly comparable, in both cases the same model inputs have been used for commodity prices, policy driven infrastructure build (e.g. new power plants, electrical transmission capacity coming onto the system as a result of government policies), power and hydrogen 'input' demand[1], and technology investment costs and parameters for new plants, energy storage and electrical transmission lines.
- The model has been run to determine both:
  - **New entry** required to ensure security of supply, at lowest total cost to the system. This includes economic new power and hydrogen generation and storage, and power transmission between GB zones
  - **The system dispatch** on a hourly basis throughout each future year being modelled
- Once these cases have been finalised, an in-depth comparison has been carried out to understand:
  - The impact on the operational level of the hydrogen backbone
  - The economic needs case for a hydrogen backbone in GB

[1] 'Input' power and hydrogen demand covers all demand that does not vary as a result of operation of the grid. Examples of 'output' demand that are calculated as part of the modelling include power used by electrolysers, and hydrogen burned in $H_2$ CCGTs



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# The Base case modelling uses well-reasoned inputs that reflect a plausible future outlook, with the $H_2$ pipeline the only input difference between cases

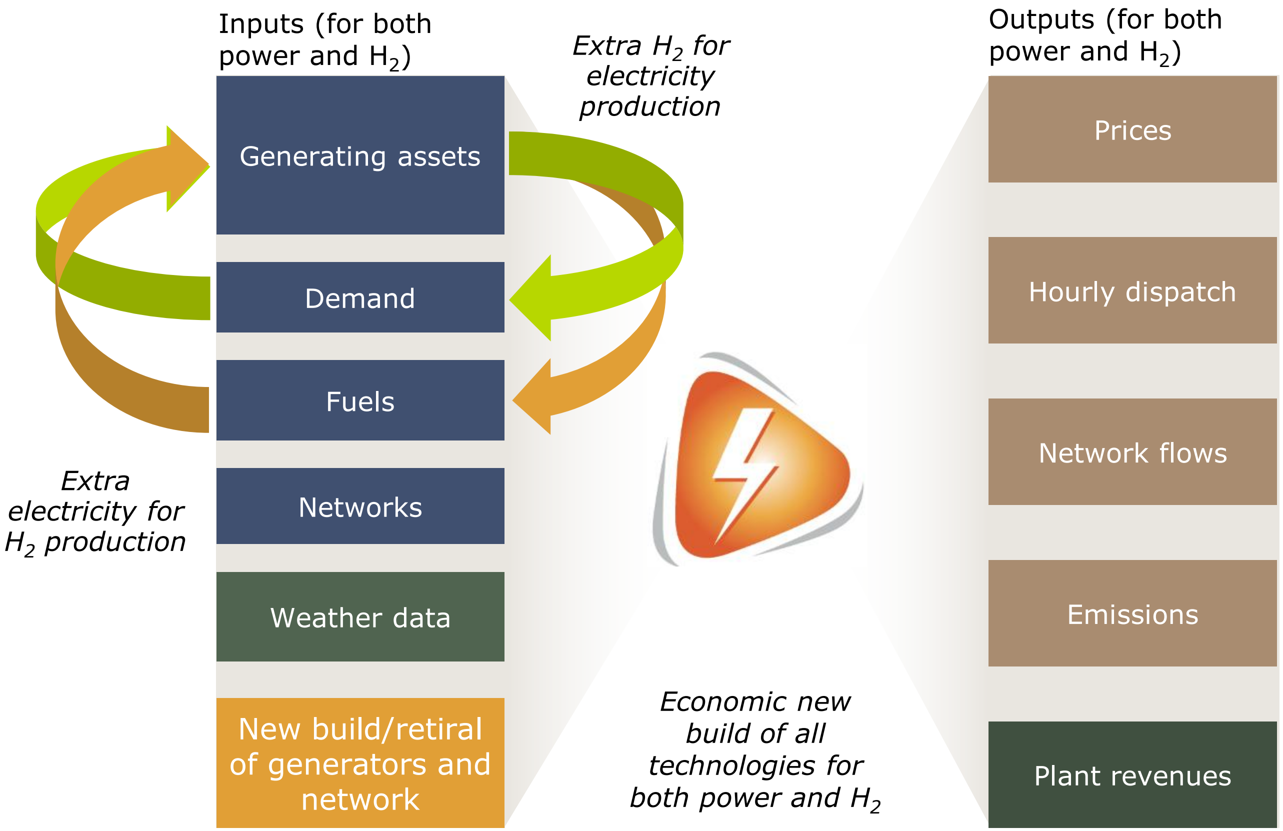
| | |
|---|---|
| **Hydrogen pipeline** | - **Different between scenarios**<br>- Counterfactual (CF): no national pipeline<br>- Backbone (BB): national pipeline capacity, with three configurations tested to find the optimal outcome. Initial configuration based on a literature review |
| **Commodity prices** | - **Same for both scenarios**<br>- **Source: DESNZ[1]**<br>- Fuel prices: fixed for future years<br>- Carbon prices: fixed for future years<br>- Hydrogen prices: modelled output reflecting modelled balance of hydrogen supply and demand |
| **Input electricity demand** | - **Same for both scenarios**<br>- **Source: CCC study[2]**<br>- Base power demand: use-case profiles used to scale demand<br>- Flexible demand: fixed profiles used to capture the price responsive behaviour of flexible power demand sectors |
| **Non-power hydrogen demand** | - **Same for both scenarios**<br>- **Source: CCC study[2]**<br>- Non-power hydrogen demand: fixed and same used in the CF and BB cases<br>- Power hydrogen demand: optimised by the model for the lowest cost solution of meeting demand |
| **GB power plants & storage** | - **Same for both scenarios[4]**<br>- Fixed capacities (e.g. existing capacity, offshore wind, nuclear) **based on the CCC study[2]** which remained the same for both scenarios |
| **GB transmission system** | - **Same for both scenarios[4]**<br>- Fixed capacity expansion of cross zonal capacities till 2035 **based on the ETYS 2023[3] plan** for both scenarios |
| **Interconnection capacities with neighbouring markets to GB** | - **Same for both scenarios**<br>- **Source: CCC study[2]**<br>- Capacities: same electricity interconnection capacity and no hydrogen interconnection in both scenarios |
| **Technology investment costs** | - **Same for both scenarios**<br>- Projections based on technology cost assumptions used in **CCC study[2]** |

Sources:
1. DESNZ, Energy and Emissions Projections 2024, October 2024
2. CCC, 7th Carbon Budget, February 2025
3. Electricity Ten Year Statement 2023; August 2024

Other notes:
4. For the BID3 Auto Build runs used to optimise the installed capacity of new entry, The same starting point has been used for installed capacity of power plants, storage and the GB transmission network in the Counterfactual and Backbone cases. The Auto Build runs then output an optimised new build installed capacity mix, which was used as an input into the BID3 Dispatch module runs to determine the hourly system operation in both cases.

# AFRY has used BID3, our in-house power and hydrogen market model, to develop the two Base scenario cases

### BID3 OVERVIEW




BID3 co-optimises the production of electricity and hydrogen, as well as the endogenous extra requirement of energy to be used by generators.

The geographical resolution in BID3 is divided into zones. The zones are the smallest geographical entities in BID3 and define the resolution of all the input data. This is shown visually in the next section.

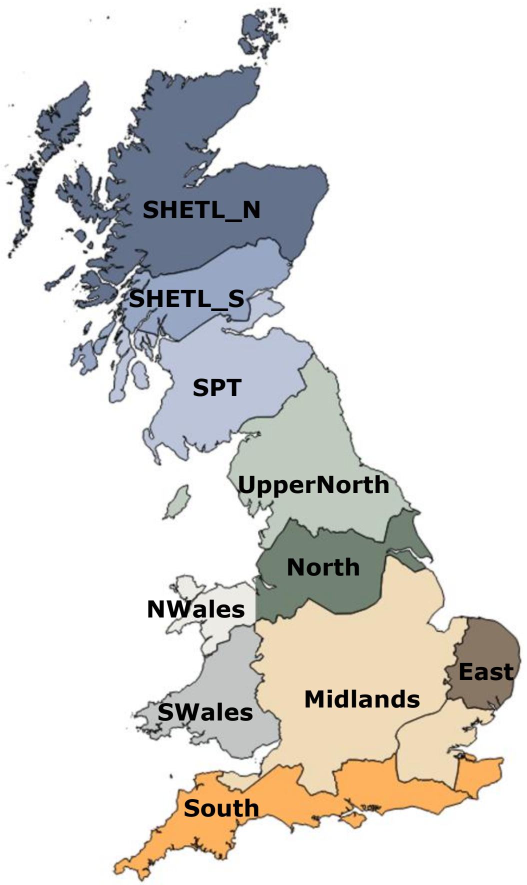
  

# Contents



# Our modelling divides GB into 10 electricity zones and 13 hydrogen zones, which form the basis for identifying hydrogen backbone connection points

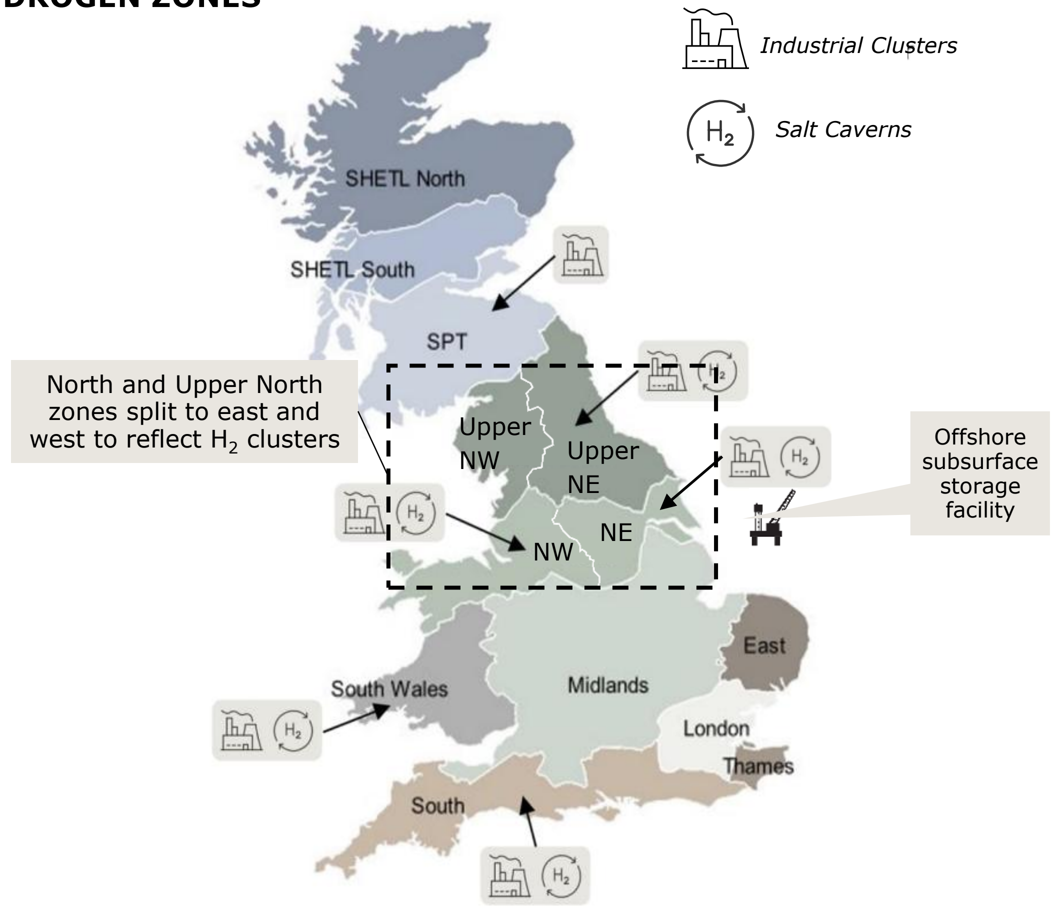
**POWER ZONES**




**Backbone configuration**

- The $H_2$ backbone was configured to connect the hydrogen zones
- An initial $H_2$ backbone was initially designed consisting of pipeline connections between key zones, informed by a literature review.
- This preliminary configuration was then refined through an iterative evaluation against a defined set of criteria as described in the following slides

**HYDROGEN ZONES**



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# AFRY configured the backbone by assessing alternative configurations, and measuring the performance of individual pipes against three key criteria

## 1 PIPE TIME SPENT AT PEAK UTILISATION

An example of a pipeline (Upper NE to NE in 2035), where it was constrained, and therefore its capacity was increased

Original – 1 GW


Current – 3.8 GW

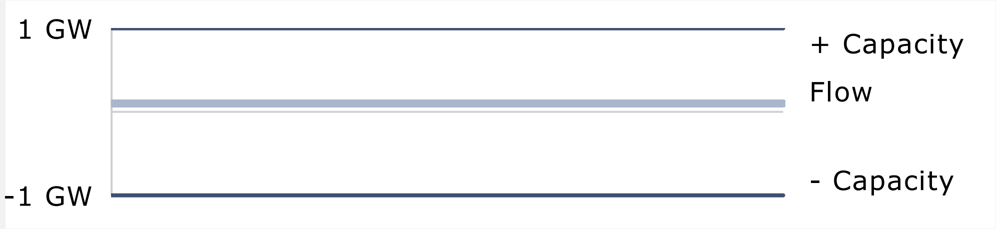

An example of a pipeline (NE to Midlands in 2045), where it was underutilised, and therefore its capacity was decreased

Original – 3 GW

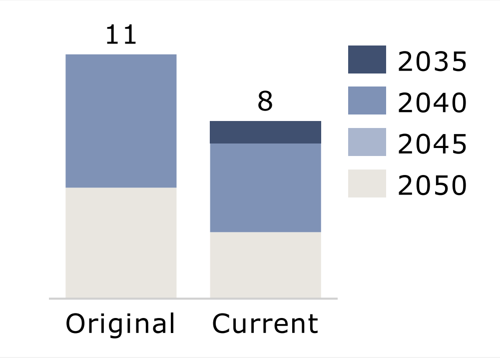

Current – 2 GW


## 2 LOWEST FEASIBLE PIPELINE CAPACITY

An example of a pipeline (Midlands to London in 2040), where the flow rate is insufficient to warrant developing the pipeline until a later year




## 3 NUMBER OF STEPS FOR PIPELINE CAPACITY ENHANCEMENT

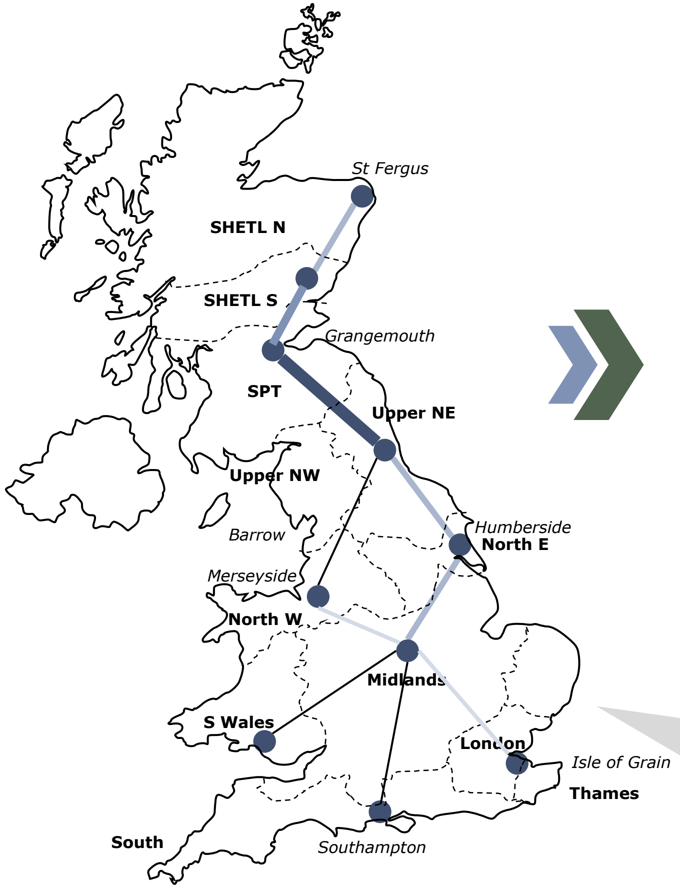



It was assumed that the backbone would be future-proof. Therefore, the number of steps were limited for capacity increase, where reasonable, in order to avoid multiple pipes being built along the same route in a short period of time.

# Throughout the refinement process, all pipelines in the initial configuration of the backbone to 2050 were maintained but capacities were adjusted

## FIRST BACKBONE CONFIGURATION IN 2050

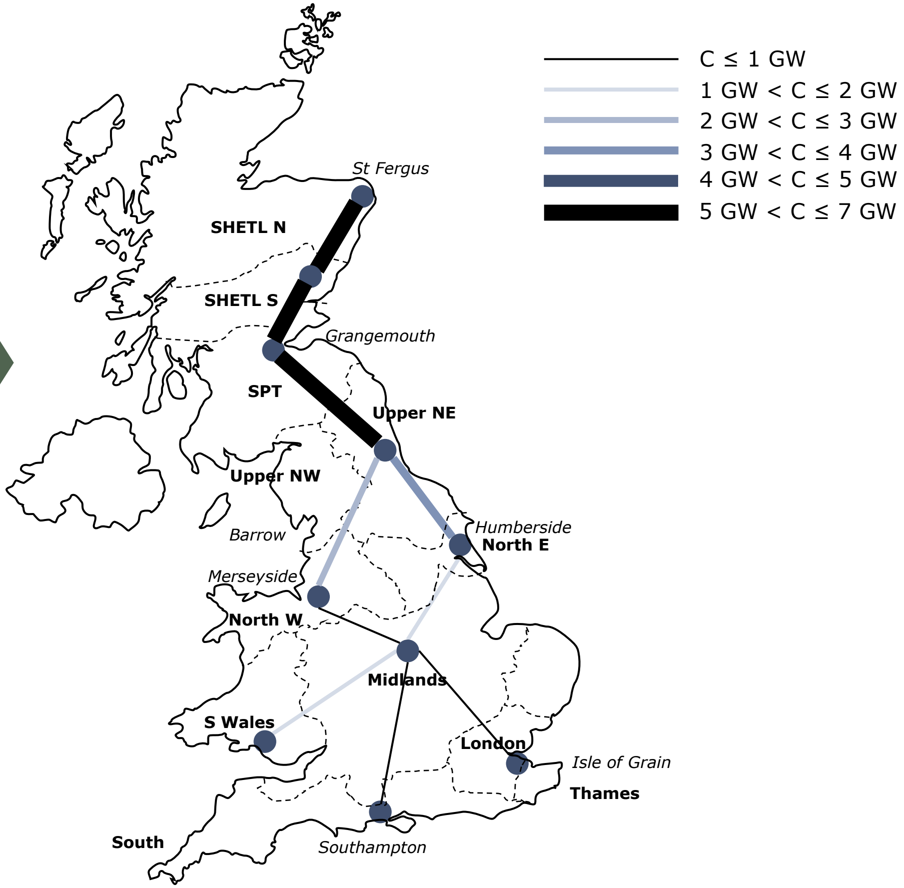



**Main adjustments:**

- Decreased capacity for links between the Midlands and northern zones.
- Decreased capacity for links between the Midlands and the southern zones of London and the South.
- Increased capacity for pipelines in Northern Great Britain.

The first configuration was based on a review of literature and recent studies (including CCC CB7 and Project Union)

## FINAL BACKBONE CONFIGURATION IN 2050



# The total capacity of the final hydrogen backbone configuration has increased compared to the initial configuration, in the medium and long term

## FINAL CONFIGURATION CAPACITIES (GW)

| Zone from | Zone to | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|
| SHETL N | SHETL S | - | 1.80 | 5.30 | 5.30 | 6.50 |
| SHETL S | SPT | - | 2.10 | 5.50 | 5.50 | 6.80 |
| Upper NE | SPT | - | 2.30 | 5.80 | 5.80 | 7.00 |
| NE | UNE | 1.00 | 3.80 | 3.80 | 3.80 | 3.80 |
| Upper NE | NW | - | 1.40 | 2.20 | 2.20 | 2.20 |
| Midlands | NW | - | 1.00 | 1.00 | 1.00 | 1.00 |
| Midlands | NE | - | 2.00 | 2.00 | 2.00 | 2.00 |
| Midlands | S Wales | - | - | 1.40 | 1.40 | 1.40 |
| Midlands | South | - | - | - | - | 0.75 |
| London | Midlands | - | - | - | 0.50 | 0.50 |

Key: Change in capacity compared to initial configuration

| Increase | Unchanged | Decrease |
|---|---|---|

## BACKBONE KEY STATISTICS

- The point-to-point length of the hydrogen network at the transmission level, spanning from zone to zone, extends to just over **1,700 kilometres**.
- By 2050 this modelled network has a total capacity of just under **32 GW**[1] and can flow ~**8400 kt/year** of hydrogen per year (assuming continuous flow and using LHV of hydrogen) or **~280 TWh/year** (100% load factor)
- For comparison, the national gas transmission network (NTS) is **7,660 km** and while the total network is approx. **284,000 km** flowing at **900 TWh/year**[2].
- The Project Union program is stated to create a hydrogen backbone of up to **1,500 - 2,000 km** through a combination of repurposed existing assets and new infrastructure[3].
- This is approximately **20-25%** of National Grid's existing NTS network (7,660 km)[3]

1 reflects the sum of rated capacities across the backbone and branch pipelines. This value represents the aggregate hydrogen transport potential of the system, assuming localised production and consumption within each branch, 2. Hydrogen UK, Recommendations for the Acceleration of Hydrogen Networks, 2023 3. Future of Great Britain's Gas Networks Report for National Infrastructure Commission and Ofgem – ARUP, 2023

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# The backbone increases deployment of electrolysers and salt cavern storage, while reducing the need for SMR, electricity transmission, and LDES

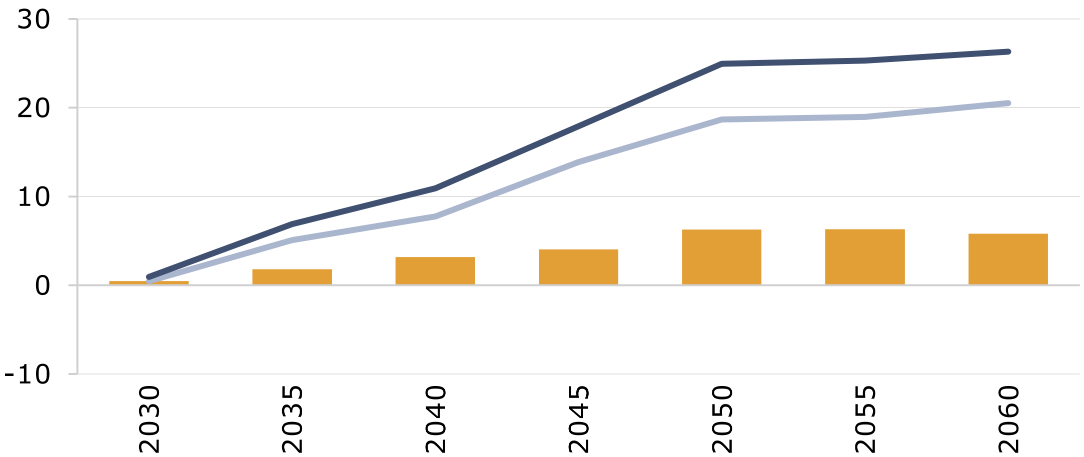
**KEY FINDINGS – MODELLED OUTCOMES OF THE SYSTEM**

| | |
|---|---|
| **1** | **Electrolysers:** The development of a hydrogen backbone increases electrolyser deployment across GB, especially in Scotland. Most of the SMR with Carbon Capture & Storage (CCS) capacity deployed in the Counterfactual is removed in the Backbone case because SMR uses relatively expensive gas, and therefore cannot compete with electrolysers in the production of hydrogen |
| **2** | **Hydrogen storage:** The backbone results in greater salt cavern storage than in the Counterfactual, noting that salt cavern storage is located in the north of England due to geological constraints. As such, the backbone allows Scottish green hydrogen to access more easily cost effective storage solutions. Hydrogen tank capacity shows only very small variations between years. |
| **3** | **Dispatchable generation:** In both Base cases, Combined Cycle Gas Turbine (CCGT) $H_2$ is the most economic low-carbon fully-dispatchable power generator in the long term. Adding a backbone enables a small amount of extra build of CCGT $H_2$ as it will get access to lower priced hydrogen from Scotland. Unabated thermal capacity remains the same between both cases as new build levels have been capped. This cap has been applied to reflect likely investor uncertainty about whether these plants will be allowed to operate long-term, making them less attractive to build |
| **4** | **Electricity transmission network:** A well-placed backbone allows for a less rapid, and lower capacity build-out of the electricity transmission network. This is because the presence of the backbone means that some of the surplus electricity in oversupplied zones can be converted to hydrogen using electrolysis, and then this hydrogen can be transported to where energy is needed via the backbone. |
| **5** | **Electricity Storage:** The backbone results in less Long Duration Electricity Storage (LDES) capacity build. This is because excess generation from renewables will be used to produce hydrogen that can be transported and / or stored, rather than being stored in LDES for long periods. Nationally (6hr duration) battery capacity remains relatively unchanged, with some regional differences reflecting the roll-out of the backbone. |
| **6** | **Renewables & emissions:** The backbone reduces both curtailment of wind generation and national $CO_2$ emissions (noting both scenarios are compliant with government emission targets by design). This is the result of excess renewable generation being utilised in electrolysers to produce hydrogen, combined with less hydrogen production from SMRs. The hydrogen produced is then able to flow across GB to where it is needed, thereby displacing more emissions intensive power generation technologies. |

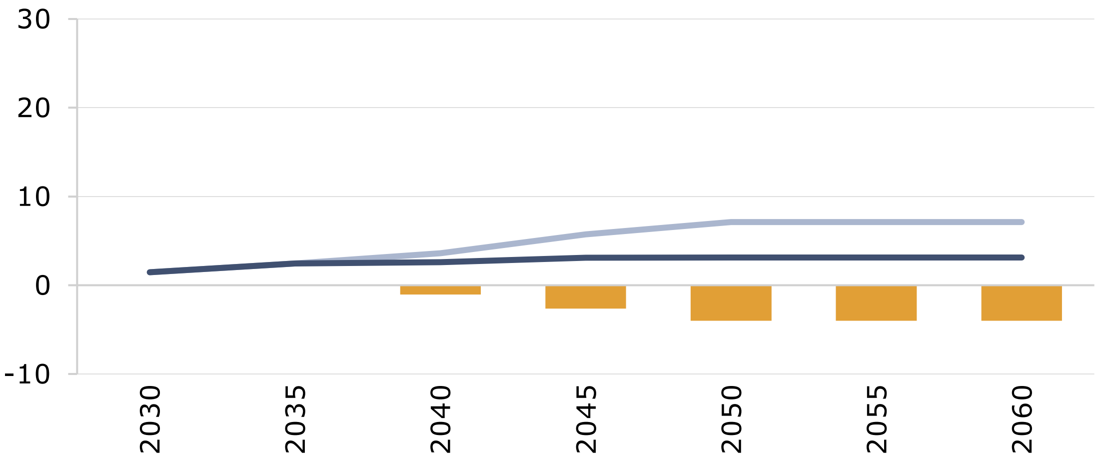
# The introduction of the backbone results in more new electrolyser capacity, and less new SMR capacity compared to the Counterfactual

CF BB BB-CF delta

**INSTALLED CAPACITY OF ELECTROLYSERS (GW)**




**INSTALLED CAPACITY OF SMR (GW)**

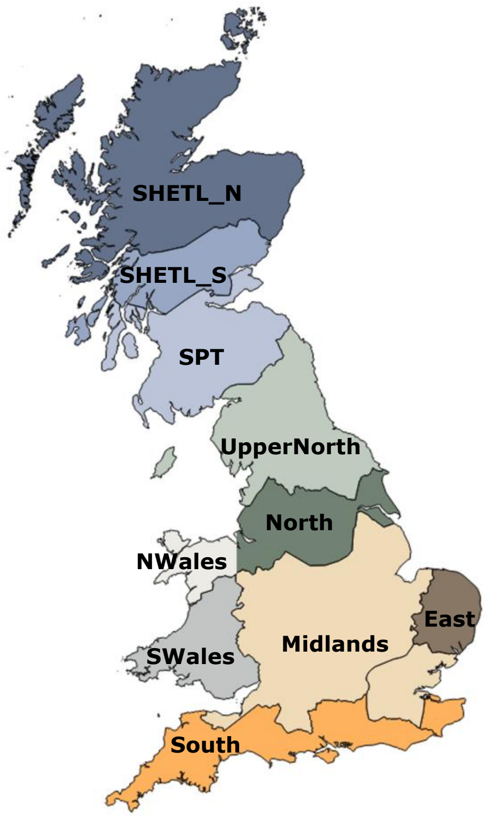


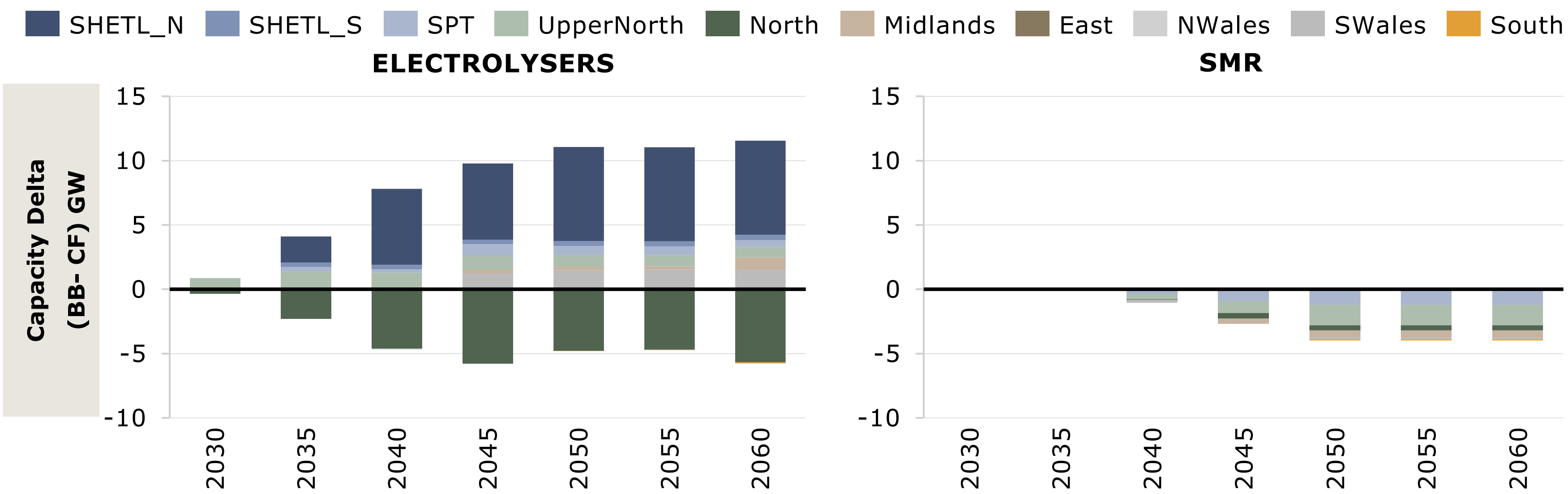

COMMENTS

- The charts show total electrolyser and SMR capacities across GB for the Backbone and Counterfactual cases.
- Key points to note include:
  - **Electrolyser capacity:** A backbone enables more electrolyser capacity overall across GB, increasing by nearly 6GW in the long term compared to the Counterfactual. This is because electrolysers are able to locate in zones with higher renewable potential, with the hydrogen produced able to travel down the pipelines to the zones with high hydrogen demand
  - **SMRs:** A backbone significantly reduces the build of additional SMRs, as it will be cheaper to build electrolysers and transport the produced hydrogen, rather than building SMRs which use relatively expensive gas, and struggle to compete. A very small amount of SMRs remain in the Midlands, South and South Wales to meet residual hydrogen demand after accounting for imports and exports.

# The majority of additional electrolyser capacity in the Backbone case is in Scotland; in the North zone some new capacity is displaced by $H_2$ imports

**GB ZONAL MAP[1]**



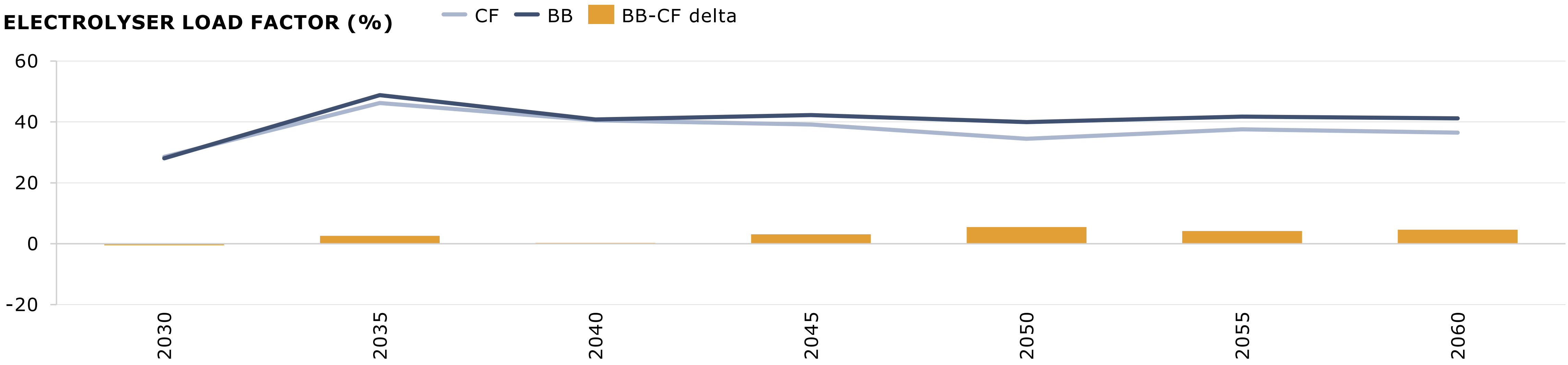

**Comments**

- The charts show the capacity delta between the Backbone and Counterfactual cases for electrolysers and SMRs across GB zones.
- Key points include:
  - **Electrolyser capacity:** The majority of additional electrolyser capacity in the Backbone case is in Scotland, while in the North zone electrolyser capacity is actually lower with a backbone. This change in distribution of electrolyser capacity results from electrolysers being able to able to be located in Scotland close to areas of high renewable generation, with the pipeline able to transport the hydrogen produced down to the hydrogen demand centre in the North zone.
  - **SMRs:** SMR capacity has decreased across all the zones connected via the hydrogen backbone. This is because it will be cheaper to transport green hydrogen rather than build relatively high cost SMRs.

1. Results have been grouped by electricity market zones

# Electrolyser load factors average at a slightly higher level with a backbone as hydrogen produced in windy locations can be transported to other regions

**ELECTROLYSER LOAD FACTOR (%)**




COMMENTS

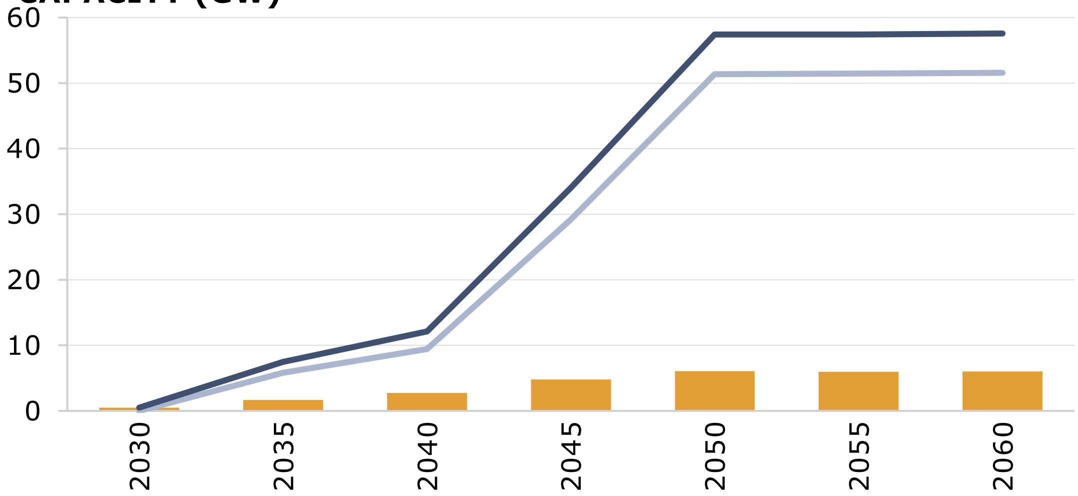
- The chart shows the electrolyser load factor across GB for the Backbone and Counterfactual scenarios. Key points include:
  - **2035 and 2040:** With a backbone, electrolyser load factors are up to 2.6 percentage points higher than in the Counterfactual case. This is because electrolysers play a greater a role in supplying hydrogen especially in regions where renewable energy sources (RES) penetration is high to meet both local demand and demand elsewhere in GB via the hydrogen backbone
  - **Beyond 2040:** With a backbone, electrolyser load factors are 4-5 percentage points higher than in the Counterfactual. This is a result of the ramp up of the hydrogen backbone especially from the North of Scotland to North of England which enables more hydrogen supply to head south. Furthermore, regions such as the Midlands and South Wales have an increase in hydrogen generation and utilisation from electrolysers to balance hydrogen supply across the South of England.

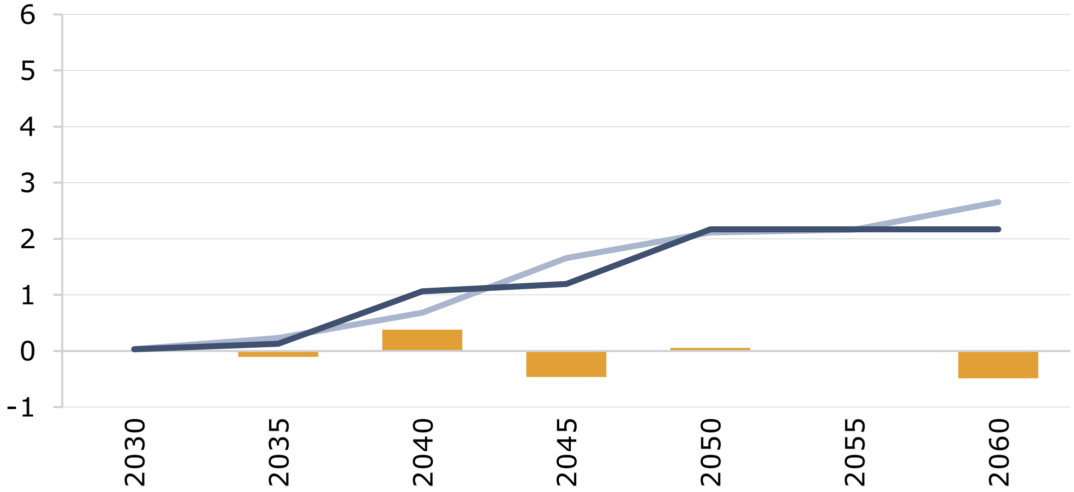
# The backbone allows more build of economically attractive salt caverns; by contrast, there is only slight variations in hydrogen tank build between cases

CF BB BB-CF delta

**ECONOMICALLY DRIVEN NEW GEOLOGICAL HYDROGEN STORAGE CAPACITY (GW)**




**ECONOMICALLY DRIVEN NEW HYDROGEN TANKS CAPACITY (GW)[1]**




COMMENTS

- The charts show capacity additions of hydrogen salt caverns and hydrogen tanks in GB for the Backbone and Counterfactual cases. Key points are:
  - **Salt Caverns:** The backbone allows c.6GW more build of salt caverns than in the Counterfactual in the long term. This is because salt caverns, which are predominantly located in the North hydrogen zones, will be able to store hydrogen transported from the Scottish zones. This stored hydrogen will then either be used to meet local demand in the North hydrogen zones, including for CCGT Hydrogen generation, or transported to other zones further south.
  - The 58 GW of salt cavern storage capacity assumed in 2050 is equivalent to approximately **44 representative salt cavern storage facilities**, each providing 320 GWh of energy over 240 hours.
  - **Hydrogen Tanks:** Relative small amounts of hydrogen tank storage is built in GB in both cases. This reflects the relative economic attractiveness of salt caverns over hydrogen tanks, when it is possible to choose between either. Only very small variations in tank capacities occur between cases.

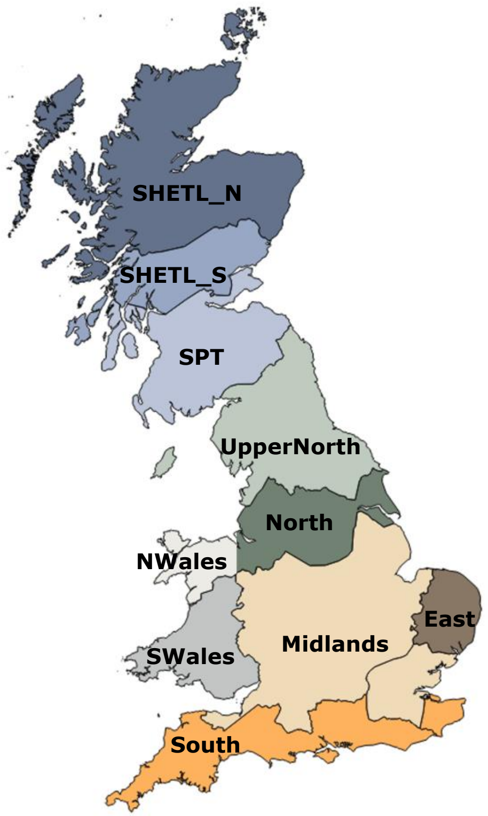
1. Note the different scale is used on the two charts shown, with far less tank capacity coming onto the system than salt cavern capacity in both cases

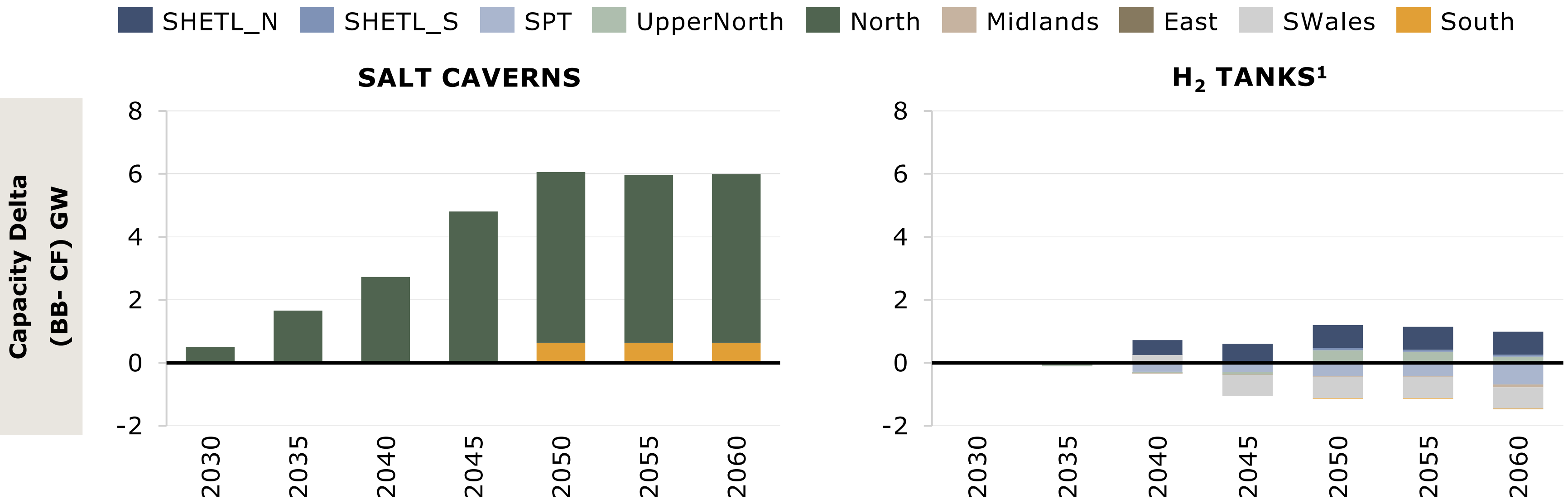


AFRY

# With a backbone more salt caverns deploy in the north zone, which is the biggest hydrogen demand centre and has potential for cavern development

**GB ZONAL MAP**




**Comments**

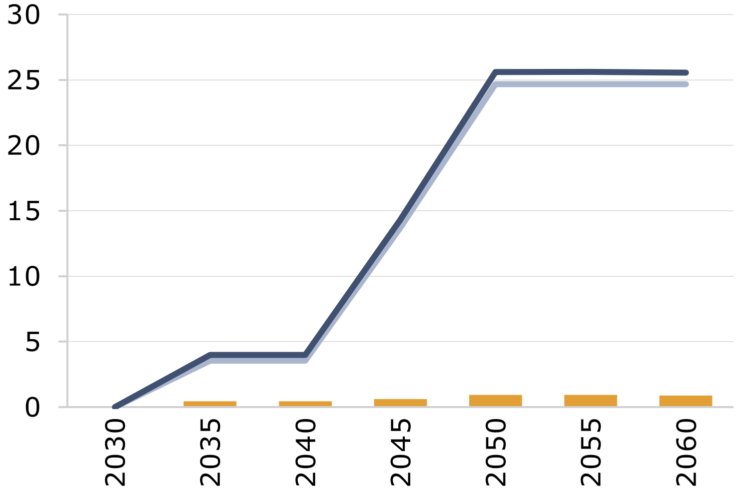
- The charts show the capacity delta between the Backbone and Counterfactual scenarios in GW for build of salt caverns and hydrogen tanks across the modelled GB zones.
- Key points include:
  - **Salt caverns:** in the Backbone case it can bee seen that the majority of additional salt caverns built in the North zone. This reflects both: a) the high hydrogen demand here, with most of GB's hydrogen clusters located within this zone; and b) the occurrence of salt caverns in this zone that are able to be converted into hydrogen storage. The North zone is connected to the Midlands which is connected to the rest of the South of GB which implies that the additional stored hydrogen could also be used to meet demand in other southern zones.
  - **Hydrogen tanks:** Scotland: More tanks built to maximise production and store low-cost hydrogen. Other regions (e.g. South Wales): Fewer tanks, as hydrogen can be transported to demand centres rather than stored locally.

1. Note the different scale is used on the two charts shown, with far less tank capacity coming onto the system than salt cavern capacity in both cases

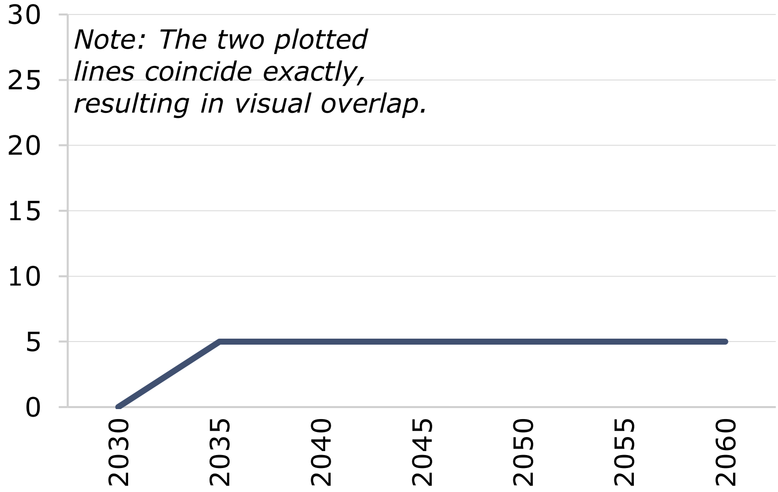
# The addition of the backbone causes only very slight changes in thermal build capacity compared to the Counterfactual

CF BB BB-CF delta

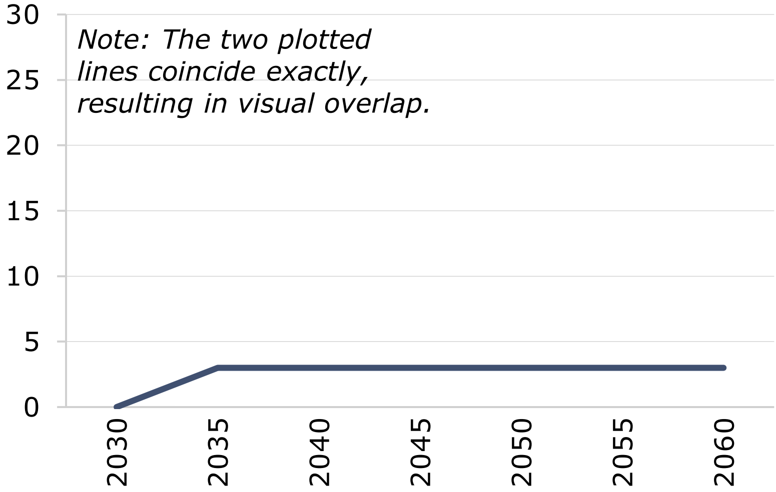
**ECONOMICALLY DRIVEN NEW CCGT $H_2$ CAPACITY (GW)**




**ECONOMICALLY DRIVEN NEW CCGT CAPACITY (GW)**




**ECONOMICALLY DRIVEN NEW GT[1] CAPACITY (GW)**

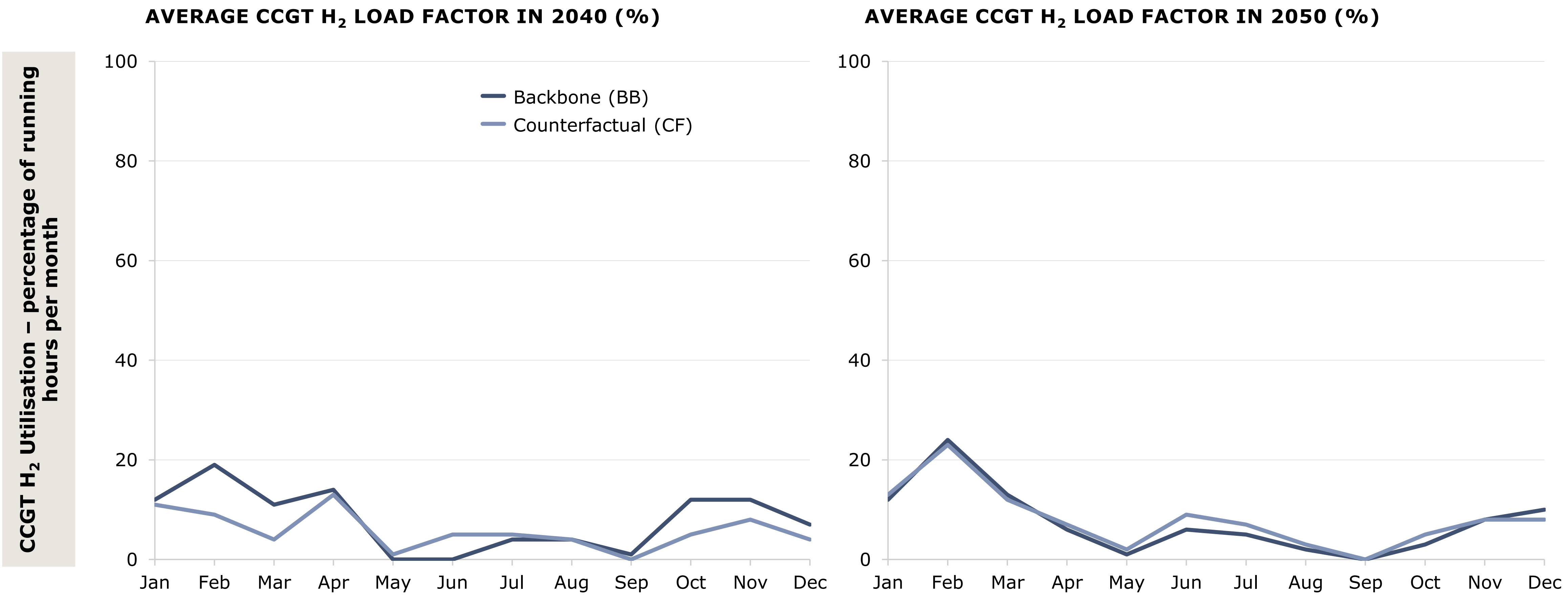



COMMENTS

- The charts show economic capacity additions of CCGT $H_2$, and unabated CCGTs and GTs across GB for the Backbone and Counterfactual scenarios. All of the additional CCGT $H_2$ capacities are located in the North zone while all the unabated CCGT and GT capacities are located in the Midlands and South zone.
- Key points to note include:
  - **CCGT $H_2$:** the backbone allows slightly more economic build of CCGT $H_2$ capacity reflecting better access to cheap hydrogen.
  - **CCGTs & GTs:** There is no difference in new build of unabated CCGTs and GTs between the two Base cases. This is because the build of unabated thermal plants in the 2030s was capped to reflect investor uncertainty about building plants that could be subject to stringent running restrictions in the near future as net-zero targets come into view. From 2040 onwards, a total ban in the scenario on new unabated thermal has been introduced.

1 – GT also known as OCGT

# CCGT $H_2$ typically run at low annual load factors in both case, behaving as a peaking plants that meet residual demand

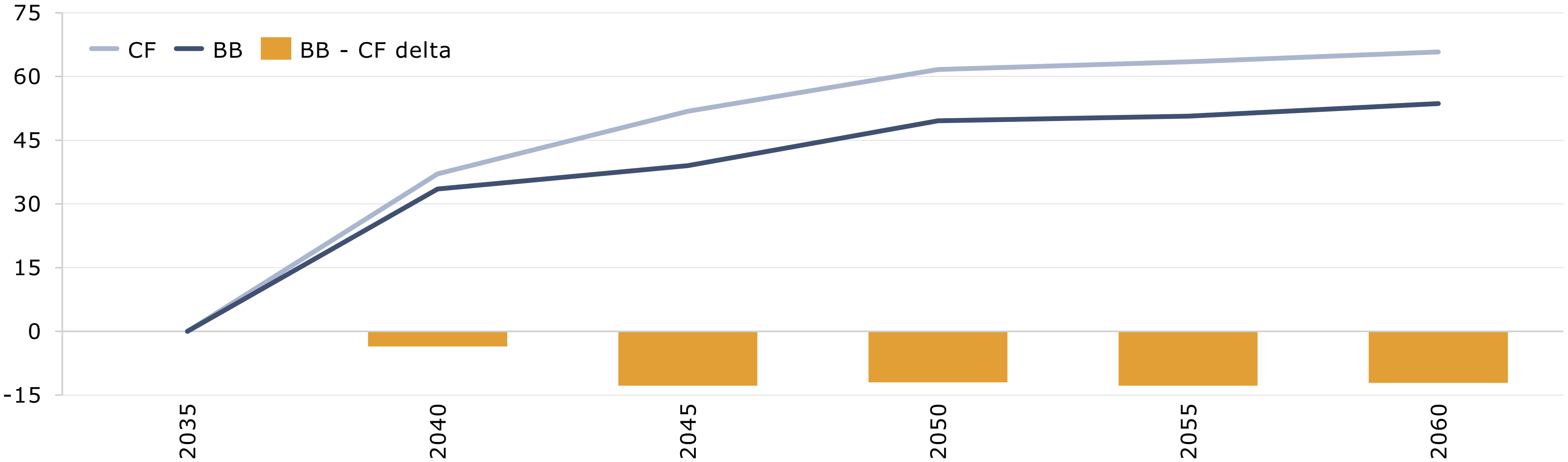



Using 2018 Case Collection

PART 1 | COMPARISON OF COUNTERFACTUAL & BACKBONE SCENARIOS

# The backbone means less new electricity transmission is required, with surplus electricity in Scotland converted to $H_2$ for transport across GB instead

## NEW ELECTRICITY TRANSMISSION INSTALLED CAPACITY FROM 2035 ONWARDS (GW)



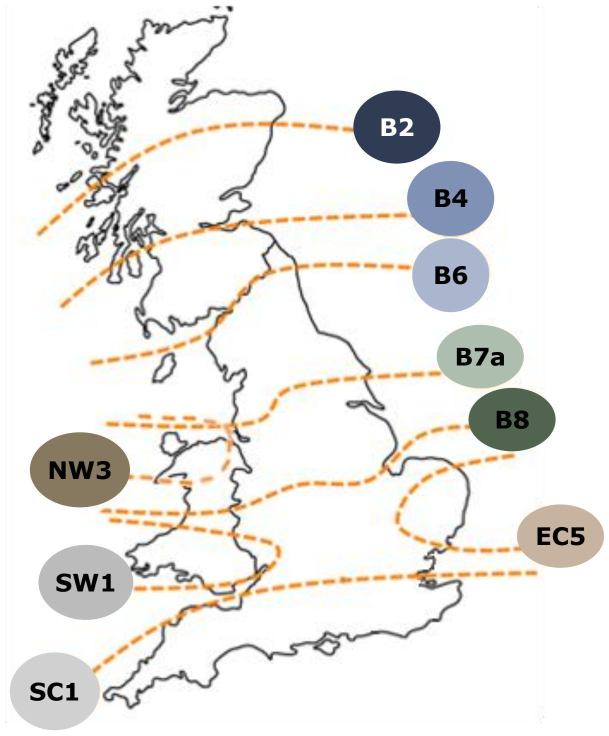

COMMENTS

- The chart above shows the additional economically driven electricity transmission network build in GB for both the Counterfactual and Backbone scenarios.
- Key points include:
  - **Backbone impact:** the addition of the backbone results in c.12GW less electricity transmissions build in GB by 2060 compared to the Counterfactual. This is because the presence of the backbone means that some of the surplus electricity in oversupplied zones can be converted to hydrogen using electrolysis, and then this hydrogen can be transported to where energy is needed via the backbone. Without the pipeline, any transfer of energy between zones would have to be via the electricity transmission grid, necessitating additional build of grid

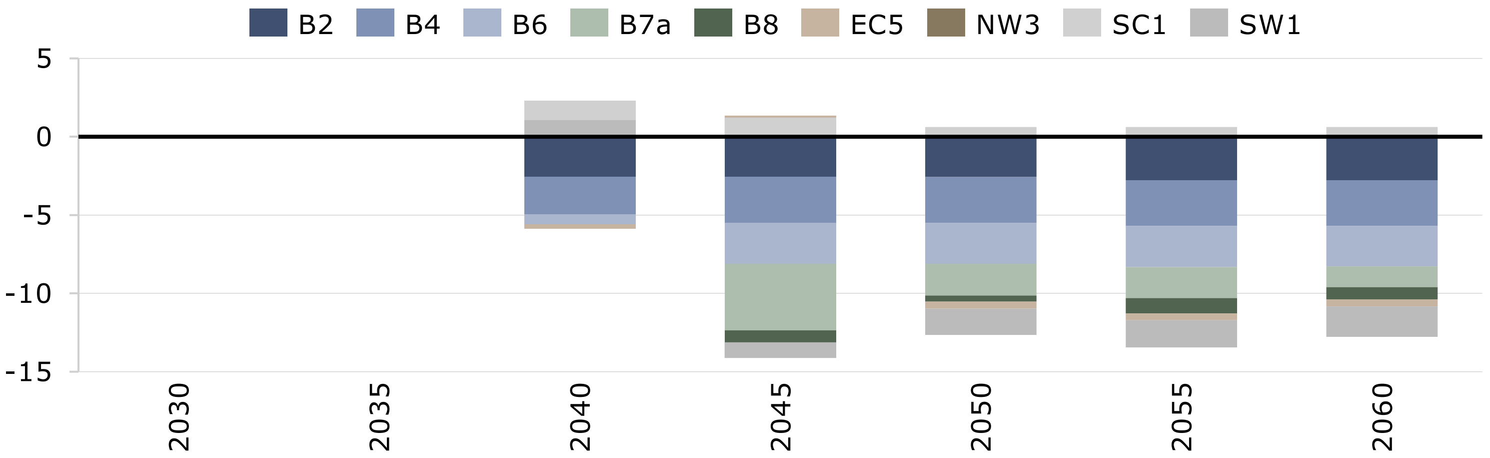
Note: The model has only been allowed to add new electricity transmission capacity in the Base scenario cases once the ETYS 2035 planned build out has occurred. It as unlikely that additional transmission capacity on top of the ETYS 2035 plan will occur in this timeframe because of long planning times to put transmission capacity in place

# The backbone results in lower transmission capacities along many northern boundaries and SW1 boundary, although SC1 boundary sees a slight increase

**GB ZONAL MAP**



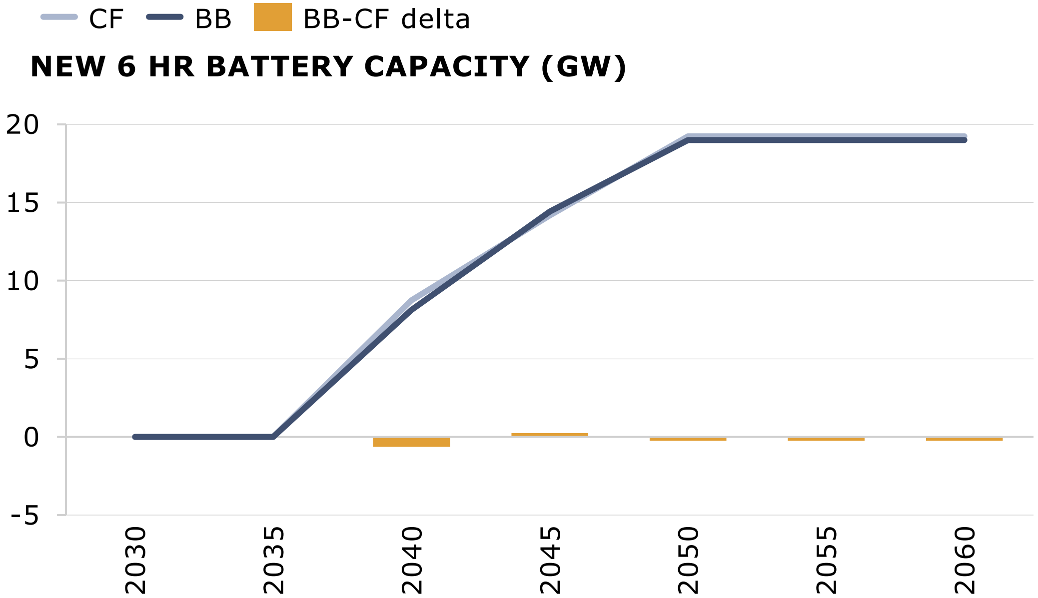

**BOUNDARY CAPACITY DELTA (BB-CF DELTA) GW**

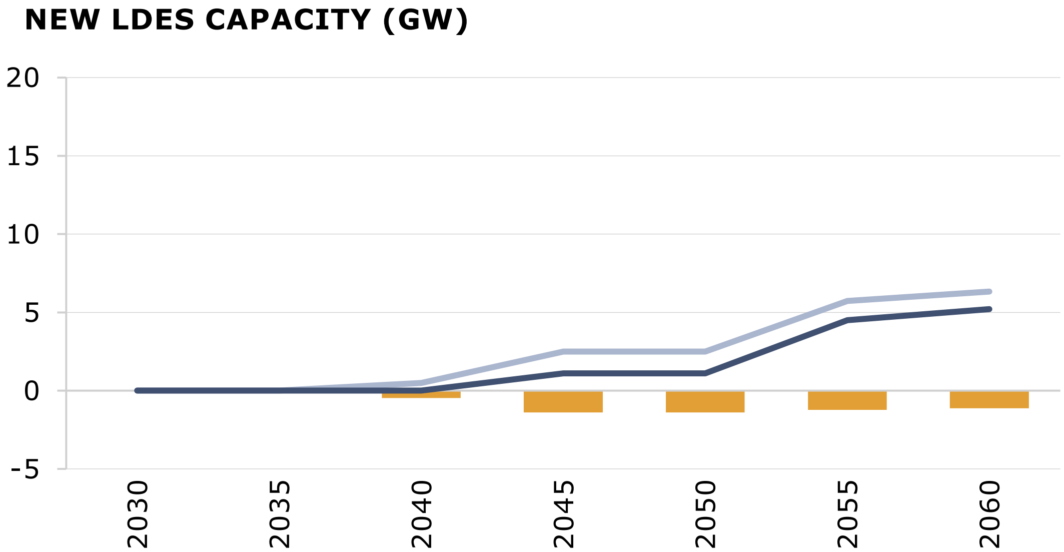



COMMENTS

- The chart above shows the transmission capacity delta between the Backbone and Counterfactual scenarios in GW for all the modelled GB zones.
- Key points include:
  - **Northern boundaries:** most of the decrease in transmission capacity when a backbone is introduced occur on the northern boundaries. This is because the backbone will make it cheaper to use the excess electricity generation from wind to produce hydrogen in Scotland for transporting south rather than building extra transmission network.
  - **Other boundaries:** with a backbone, there are some extra reductions from the SW1 boundary connecting South Wales to the Midlands due to a cheaper flow of hydrogen rather than power from South Wales to Midlands. There is a slight increase in the SC1 boundary due to higher onshore and battery build in the Midlands enabling cheaper electricity flow to the South.

# The backbone drives a reduction in LDES capacities compared to the Counterfactual, with 6 hr battery capacities relatively similar in both cases



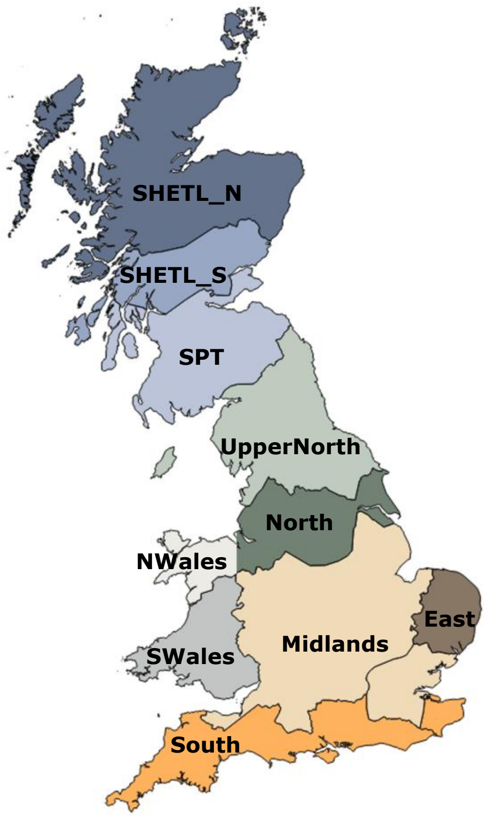



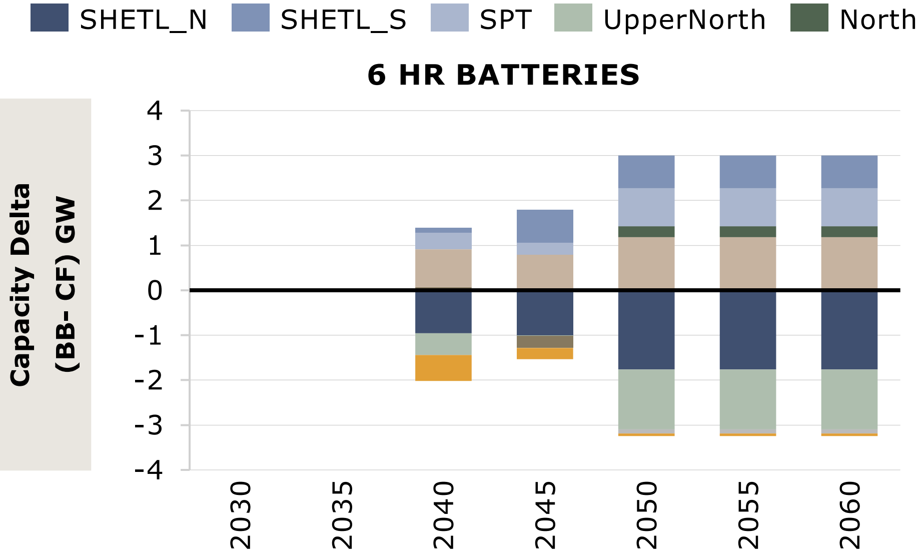

COMMENTS

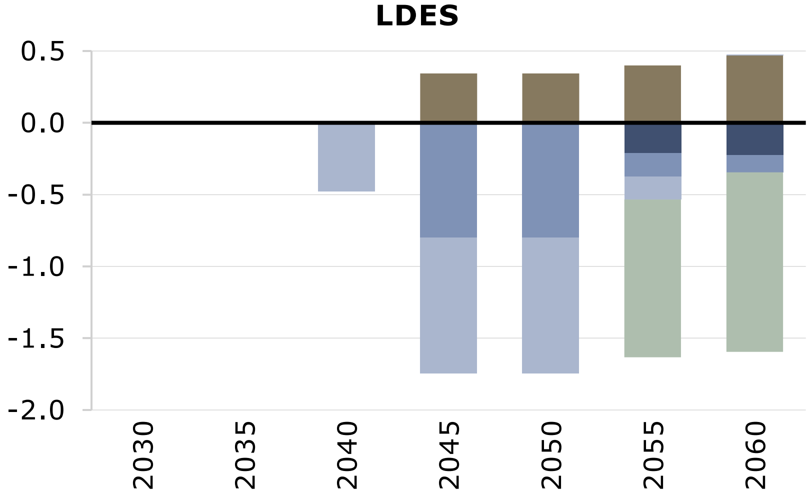
- The charts show capacity additions of 6 hr batteries, and LDES in GB for the Backbone and Counterfactual scenarios.
- Key points include:
  - **6 hr batteries:** at a national level, adding the backbone will cause only very slight variations in 6 hr batteries across the modelling period. The regional picture is more mixed (see next slide for more details).
  - **LDES:** LDES capacity is reduced by c.1 GW by 2060, predominantly in the northern zones as the availability of the backbone reduces the need to store excess power from wind for longer durations as it can be used to produce hydrogen via electrolysers for storage instead.

# With a backbone, battery capacity increases in some zones and decreases in others; LDES reduction is mainly in the Scottish and northern English zones

**GB ZONAL MAP**




**Comments**

The charts above show the capacity delta between the Backbone and Counterfactual scenarios in GW for 6 hr batteries and LDES across the modelled GB zones. Key points include:

- **Batteries:** the backbone results in shifting of locations of 6 hour batteries, however, the picture at a national level is relatively unchanged. Reduction in some regions: Where hydrogen production or strong demand centres dominate, excess RES is directed to electrolysers rather than batteries. Increase in Scotland (e.g. Shetland, SPT): More batteries to absorb excess RES from northern regions or for storing then supplying electrolysers. Strongest growth in Midlands: Well-connected location enables high flexibility - storing RES and supporting both demand and hydrogen production.
- **LDES:** the backbone results in less LDES in the Scottish zones from 2040, and in Upper North from 2055, compared to the backbone. This is because rather than building expensive LDES technologies, much of the excess renewable generation that would have put into LDES in the Counterfactual, will instead be used to produce hydrogen and transported via the pipeline to where energy is needed.

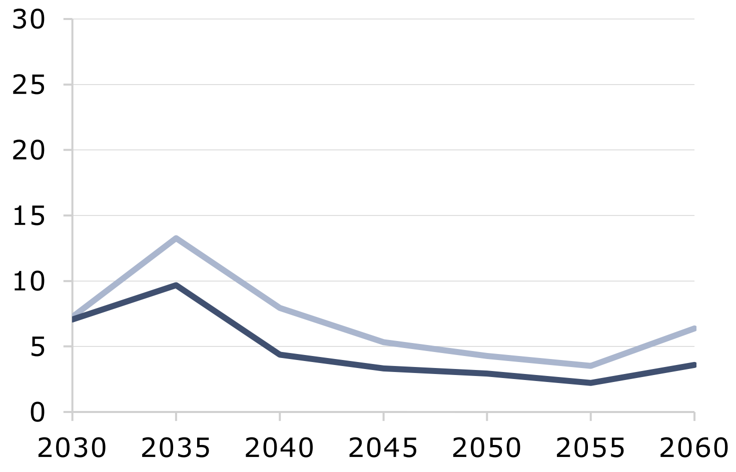


AFRY

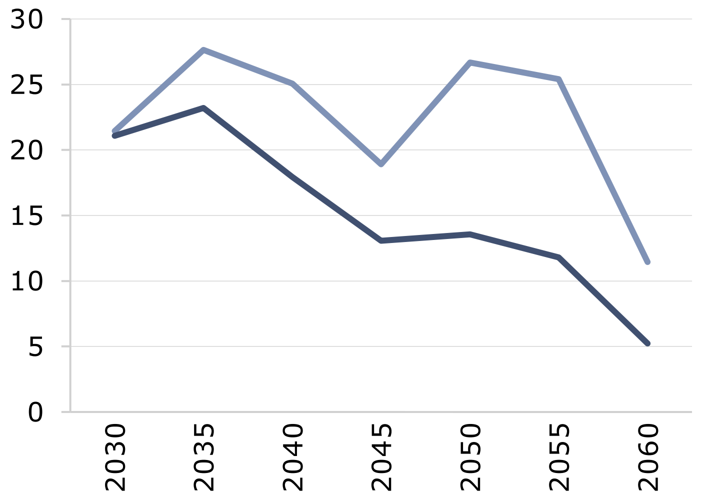
# There is less renewable curtailment with a backbone as excess power can be converted to hydrogen in electrolysers for transportation via the pipelines

CF BB

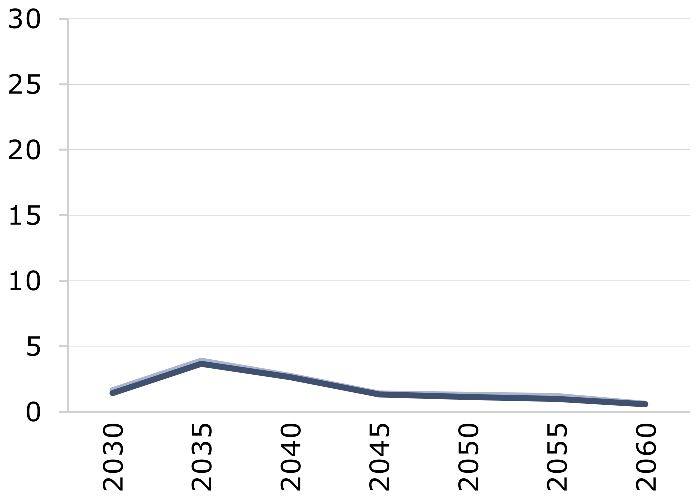
**OFFSHORE WIND CURTAILMENT (%)**




**ONSHORE WIND CURTAILMENT (%)**




**SOLAR PV CURTAILMENT (%)**



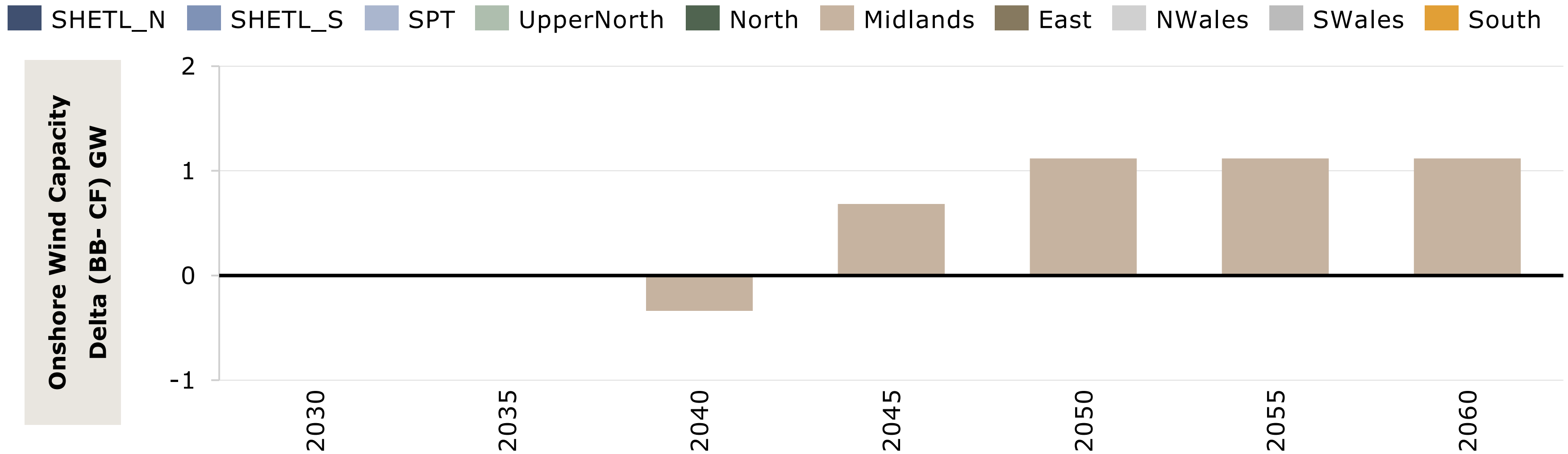

COMMENTS

- The charts show the curtailment levels by resource of offshore wind, onshore wind, and solar PV across GB for the Backbone and Counterfactual scenarios.
- Key points to note include:
  - **Drivers for reduced curtailment:** With a backbone, a higher proportion of excess renewable generation can be converted to hydrogen via electrolysis for transportation to other zones with greater hydrogen demand and / or storage potential. Without the pipeline more of this excess power is curtailed
  - **Types of renewables curtailed:** Wind is the technology that sees the biggest decrease in renewable curtailment with a pipeline. This is because the backbone configuration used connects zones with high levels of wind generation, especially in Scotland to hydrogen demand centres in the north of England. Conversely, the backbone does very little to reduce curtailment of excess solar generation.

# The Backbone enables more green hydrogen production, which increases the profitability of onshore wind in Midlands through reduced curtailment

**GB ZONAL MAP**


**Comments**

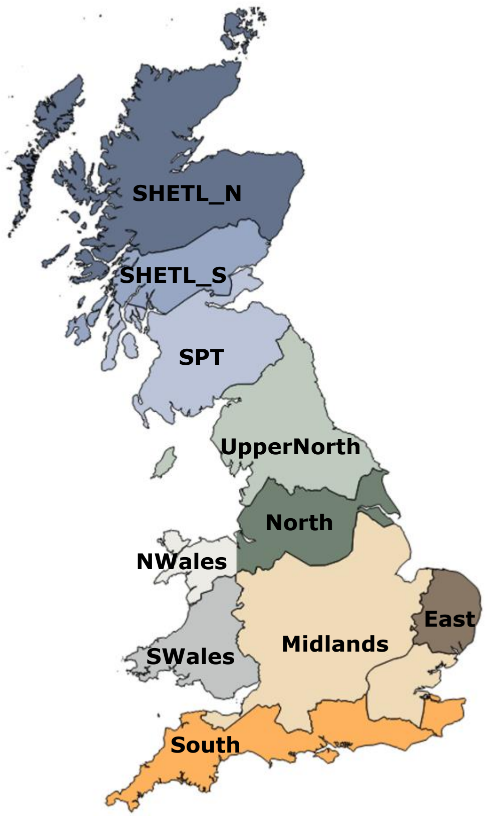
- The chart above shows the onshore wind capacity difference in GW between the Backbone and Counterfactual scenarios across the modelled GB zones.
- Key points include:
  - **The Midlands:** the backbone allows a slight increase in onshore wind capacity from 2045 onwards in the Midlands. This is because curtailment levels for onshore wind decrease here due to increased hydrogen production via electrolysis. This increases the profitability of onshore wind making it more attractive to build. The slight decrease in onshore wind in 2040 in the Midlands reflects the cheaper hydrogen imports from North which reduces slightly hydrogen production from electrolysers, making onshore wind marginally less profitable to build in 2040
  - **Other zones:** An increase in onshore wind in other zones has not been observed, as even with electrolysis reducing curtailment, the economics for this do not stack up

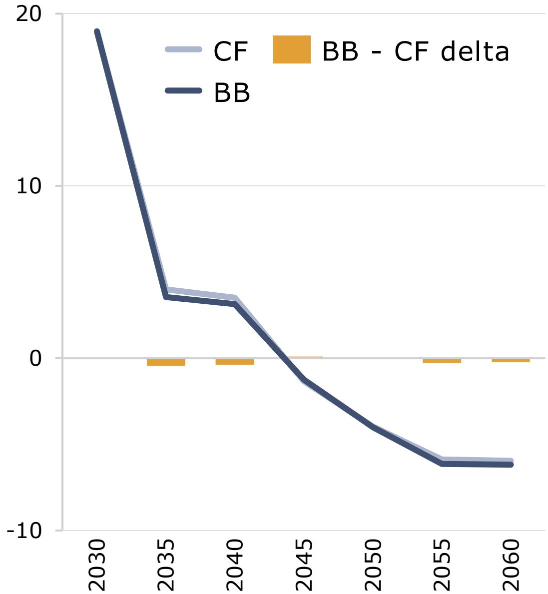
AFRY

# Both Base cases meet UK decarbonisation targets by design through policy build; the backbone reduces emissions further marginally in most years

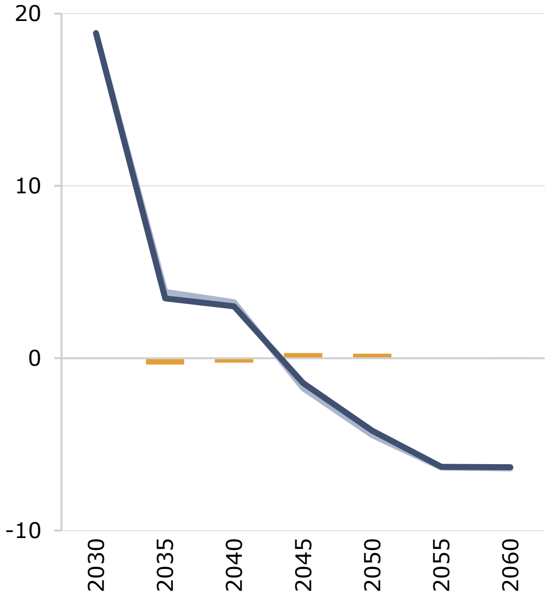
## GB ZONAL MAP



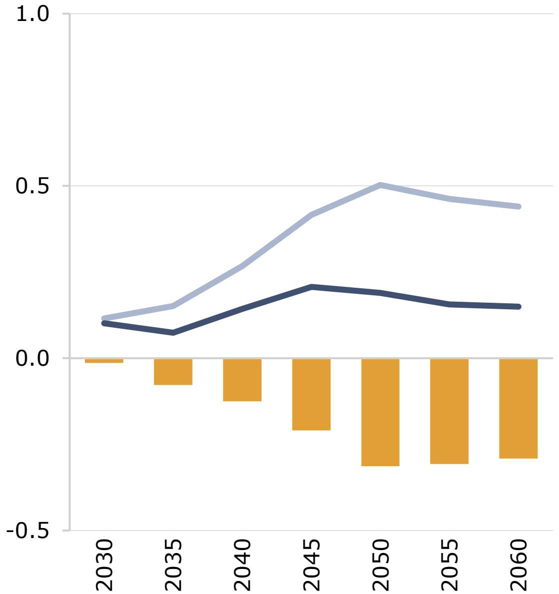

## TOTAL EMISSIONS MTCO2




## POWER GEN EMISSIONS MTCO2




## $H_2$ EMISSIONS MTCO2




**Comments**

- The charts show the difference in emissions in $mtCO_2$ from the power and hydrogen sectors between the Backbone and Counterfactual cases across GB zones.
- Key points include:
  - **Policy compliance:** both the Counterfactual and Backbone cases are designed to meet government decarbonisation targets. This is achieved via policy build included exogenously to the modelling process to ensure compliance.
  - **Variation between cases:** Adding the backbone reduces renewable (zero emission) curtailment levels and results in less build of SMR with CCS, which causes a decrease in emissions across most of the modelled period.

# Contents



# Our approach is designed to evaluate the economic case for a national hydrogen backbone, aligned with the study's objective

The objective is to answer the question: Is there a positive economic reason for a national hydrogen network?

**APPROACH:**

Whether the changes in technology mix and operating patterns modelled in the Base scenario deliver societal benefits depends on the extent to which commercial and non-commercial benefits can be achieved:

1) **Commercial benefits**:
   - An economic assessment of:
     - Total system costs
     - Net Present Value (NPV)

   to understand whether a $H_2$ backbone can generate more value than it costs

2) **Non-commercial benefits**:
   - An assessment of whether a hydrogen backbone can generate additional value from other benefits not falling under Commercial benefits, including those associated with:
     - Environmental & climate impact
     - System integration
     - Security of supply
     - Economy, employment and skills

   Metrics for these and the selection of those to be quantified are discussed in the next section and will utilise analysis from the Base case modelling.

**PART 1 COMMERCIAL BENEFITS APPROACH:**

1. Modelled two scenarios (the Counterfactual and Backbone cases) under the Base case scenarios
2. Quantified the system-wide cost differences, allowing direct comparison of economic performance in the form of CAPEX, and fixed and variable OPEX
3. Calculated metrics such as the Net Present Value (NPV) of total system cost and yearly undiscounted spending
4. Conducted a final comparison between the two scenarios (Counterfactual / Backbone) to gauge the scale of the commercial benefits with/without a backbone

# Contents



# To quantify the backbone costs for the commercial benefits assessment, a series of key assumptions have been made

## BACKBONE SUMMARY INPUTS

**Backbone Pipeline Summary**

- **Transmission-Level Focus:** Only includes transmission level pipeline
- **Geographic Assumptions:** Transmission distances between zones are assumed as straight-line paths. These distances are pre-calculated and hard-coded for each zone-to-zone connection.
- **5-year** build time assumed

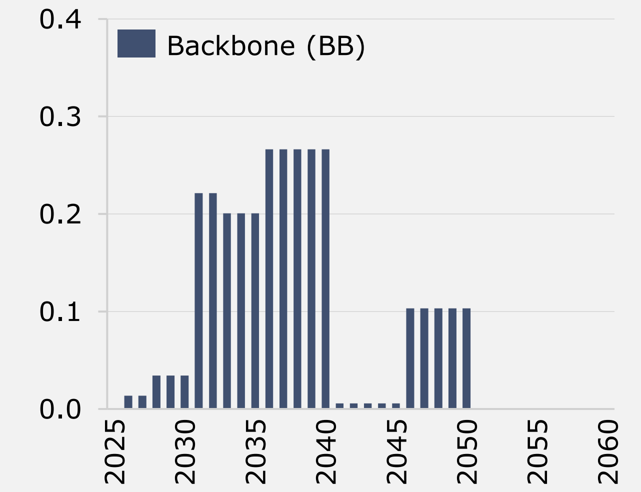
| Zone from | Zone to | Length (km) |
|---|---|---|
| SHETL N | SHETL S | 312 |
| SHETL S | SPT | 112 |
| Upper Northeast | SPT | 192 |
| Northeast | Upper Northeast | 128 |
| Upper Northeast | Northwest | 140 |
| Midlands | Northwest | 113 |
| Midlands | Northeast | 96 |
| Midlands | S Wales | 192 |
| Midlands | South | 304 |
| London | Midlands | 112 |

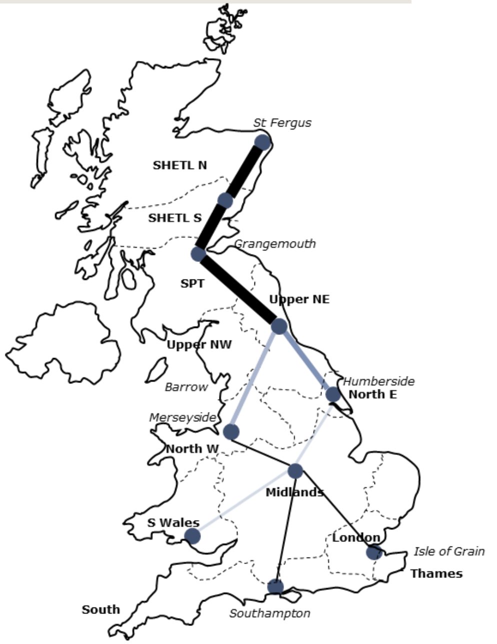
## BACKBONE SUMMARY OUTPUTS

**Backbone Pipeline Summary**

- **1,700 km** of transmission level pipeline
- By 2050 the modelled network has a total capacity of ~**32 GW** (aggregating across branches)
- Just over **£3 billion** in summed undiscounted CAPEX (Real 2023) and just over **£1 billion** in compressor CAPEX
- **0.53 £/kW/km** used for CAPEX estimates of the pipeline

### ANNUAL HYDROGEN PIPELINE CAPEX - SPREAD BY BUILD TIME (£ BILLION, REAL 2023)



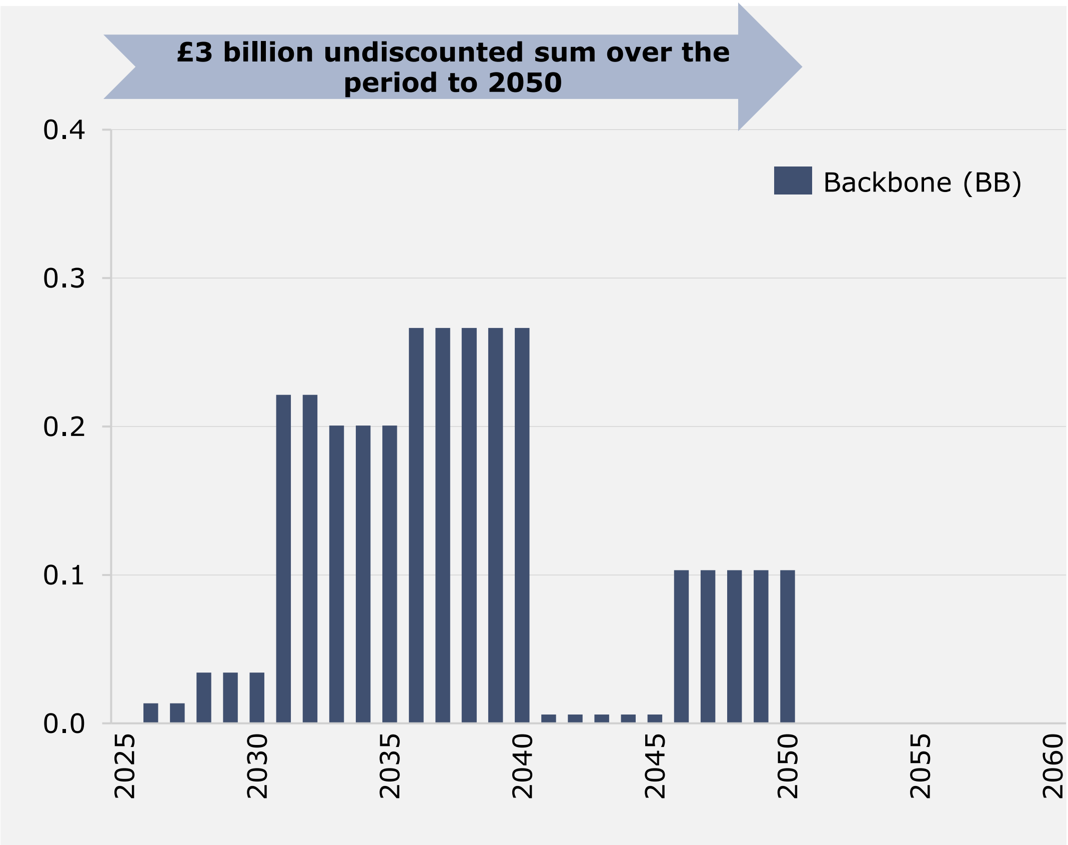



AFRY

RESTRICTED

# The capital cost estimates for hydrogen transmission pipelines vary significantly across studies, with wide-ranging per-kilometre figures

**ANNUAL HYDROGEN PIPELINE CAPEX - SPREAD BY BUILD TIME (£ BILLION, REAL 2023)**




**COMPARISON WITH LITERATURE**

- The summed undiscounted cost of the pipeline network which is based on the NTS level only comes to just over **£3 billion –** this represents just over **1,700 km** of transmission infrastructure totalling **32 GW** by 2050, equivalent to **~£1.8 million per km.**
- A study by Arup (October 2023), commissioned by the National Infrastructure Commission (NIC) and Ofgem, estimates an undiscounted pipeline CAPEX of just over **£12 billion** for 1,525 km of new build hydrogen transmission pipeline. Although pipeline capacities are not specified, the Balanced Scenario used in the study aligns most closely with our hydrogen demand assumptions.
  - Equivalent to **£8 million per km**
- While not UK-specific, a report prepared for the European Hydrogen Backbone (EHB) by Guidehouse in April 2022 estimated CAPEX figures that serve as a comparative benchmark:
  - New-build hydrogen pipelines: €1.4–3.4 million/km (2022) or equivalent to **£1.3 million** to **£3 million per km** (2023)
- These disparities likely reflect differences in assumptions (such as pipeline capacity), route complexity, construction methods, regulatory environments, and contingency allowances. The high costs in the Arup study may suggest conservative assumptions, more challenging terrain, or greater technical or regulatory requirements. In contrast, the EHB estimates may assume more favourable conditions or leverage existing infrastructure and reflect lower prices on the continent.

# Contents





AFRY

# The economic case for a backbone under the Base scenarios appears limited, with minimal difference in total system costs with or without a backbone

## KEY MESSAGES

**1**

Both cases are closely aligned on:

- Total annual system costs through 2060
- Total undiscounted costs through 2060
- Net present value (NPV).

The Backbone scenario's NPV is marginally lower than that of the Counterfactual scenario, differing by less than 1%.

**2**

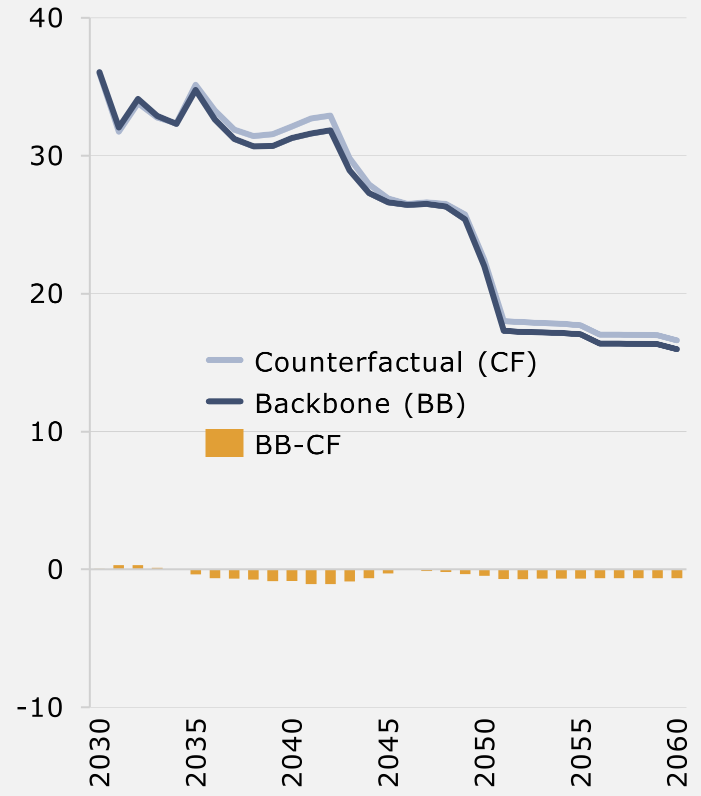
Although the NPV of both scenarios is very similar, notable differences exist in the contributions of various technologies. Specifically, electrolysers and CCGT Hydrogen play a larger role in the Backbone scenario, whereas SMR-CCS and electricity transmission have greater contributions in the Counterfactual scenario.

**3**

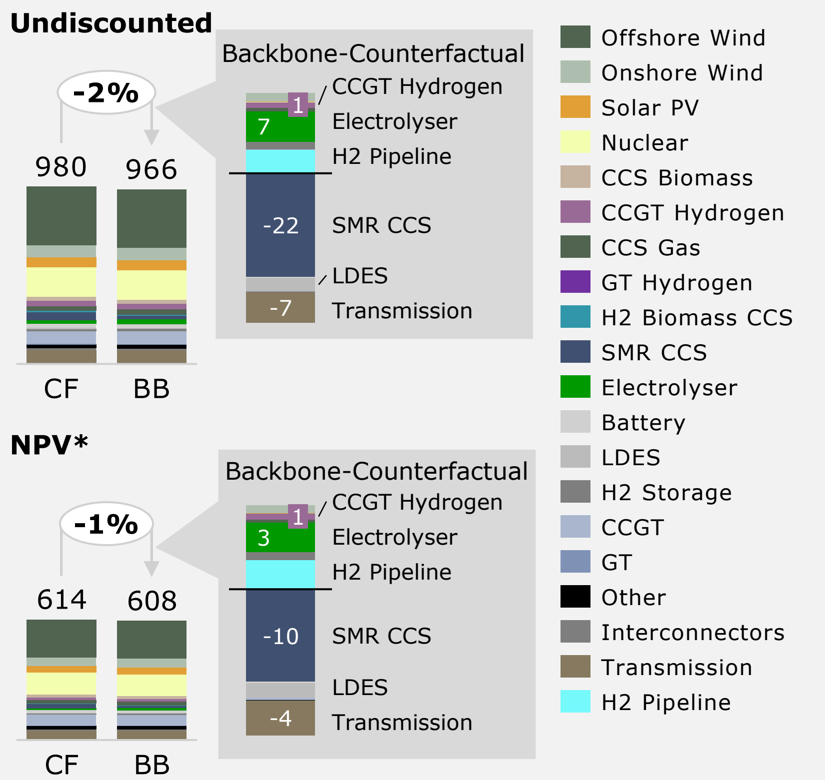
In both scenarios, increased spending occurs primarily in the 2030s, largely due to elevated CAPEX. During the 2040s, CAPEX expenditures decrease, whereas fixed OPEX rises. By the 2050s, CAPEX spending is minimal, and the growth in fixed OPEX also decelerates, leading to a more stable annual system cost.

## SYSTEM COST COMPARISON

ANNUAL SYSTEM COST (BN £, REAL 2023)



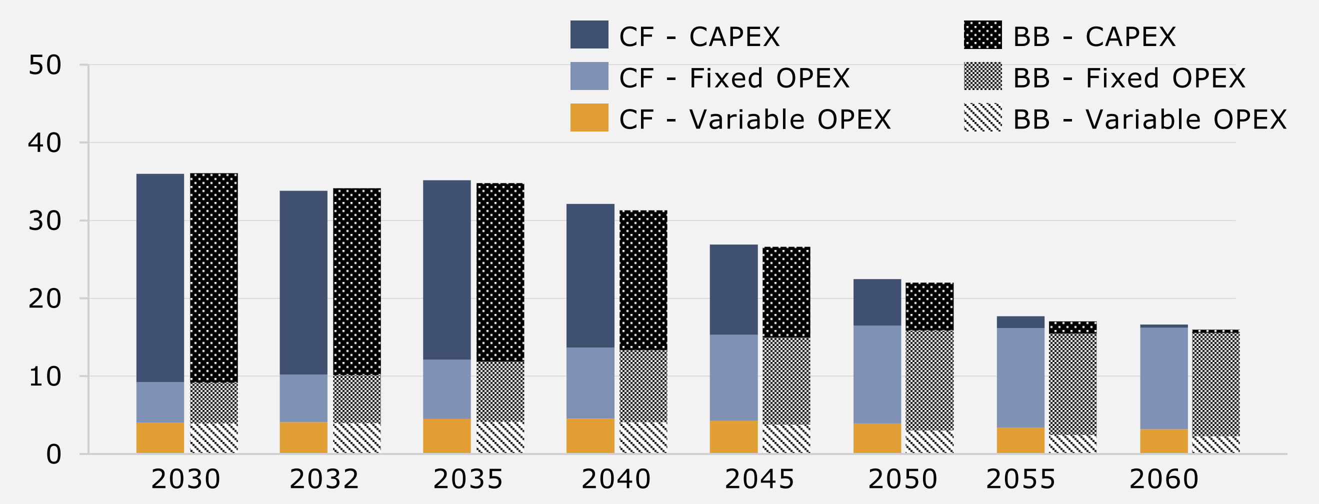

TOTAL SYSTEM COST BY TECHNOLOGY (BN £, REAL 2023)



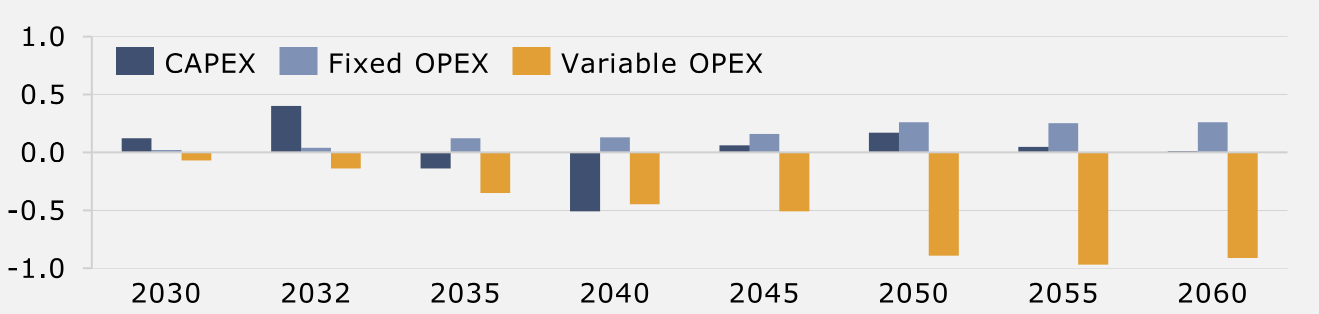

Notes: CF – Counterfactual scenario, BB – Backbone scenario.
* NPV is on a 35-year (2025-2060) period using a rate of 3.5% for the first 30 years and 3% for the last 5 years

# In both cases, the system transitions from being predominantly influenced by CAPEX to being primarily driven by OPEX

**ANNUAL SYSTEM COST (BN £, REAL 2023)**




**ANNUAL SYSTEM COST DIFFERENCE (BB–CF DELTA, BN £, REAL 2023)**




**KEY MESSAGES**

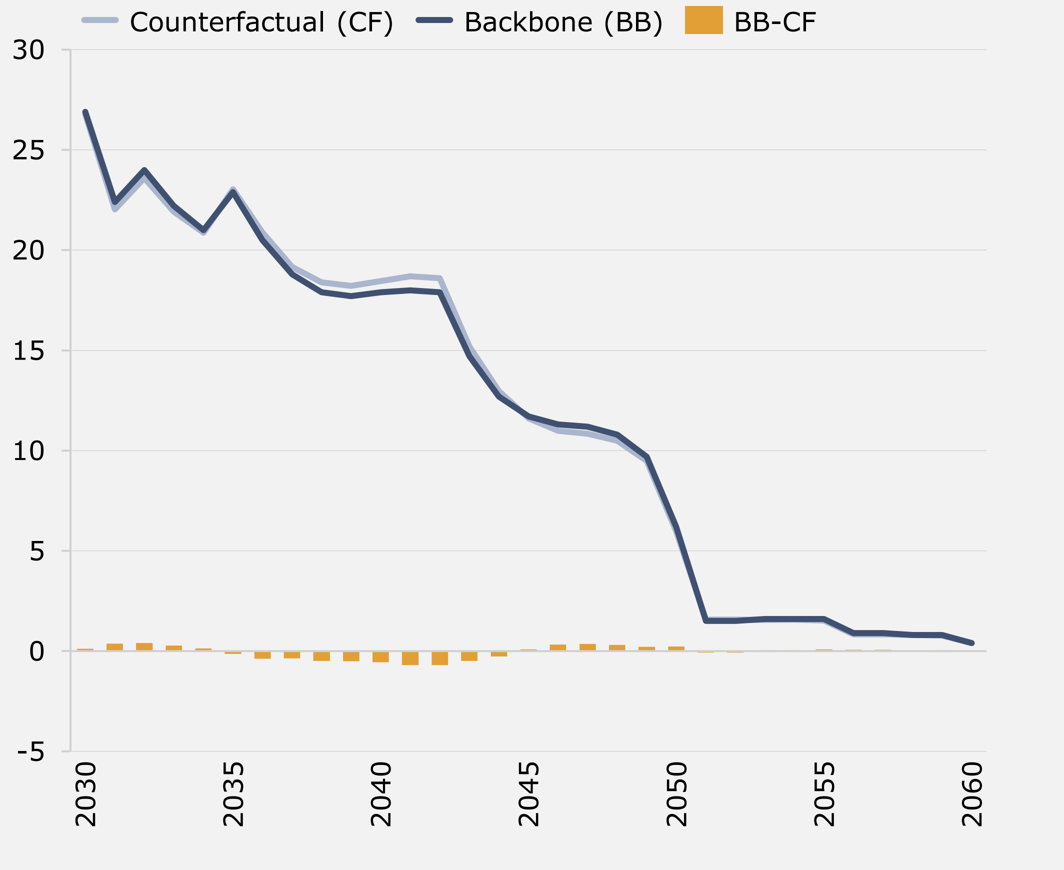
- **Overall trends:**
  - In both Base scenario cases, there is a transition from annual system costs being dominated by CAPEX to fixed OPEX becoming the largest cost driver. This reflects the following drivers:
    - CAPEX: initially there is high spend as power plants, energy storage and transmission is built to keep up with rapidly rising power demand. Longer-term, spending declines as demand growth slows, so less new capacity is needed
    - Fixed OPEX: offshore wind increasingly dominates the system, passing through its very high OPEX costs
- **Backbone vs Counterfactual:**
  - Annual system costs are very similar in both scenarios
  - CAPEX in the short-term (out to 2032) is higher with a backbone, whereas in 2040, the backbone CAPEX in the backbone is higher as more LDES and transmission are built in the Counterfactual
  - The difference in variable costs with and without a backbone increase overtime. This difference is primarily driven by greater dependence on more expensive gas in the Counterfactual case, while the backbone puts downward pressure on fuel costs as green hydrogen production increases

Notes: Notes: CF – Counterfactual scenario, BB – Backbone scenario. Variable OPEX includes: Fuel and start-up costs, CO2 costs and VOWC

# The addition of the backbone leads to a slight reduction in CAPEX spend in the mid-term, due to a fall in transmission and LDES build-out

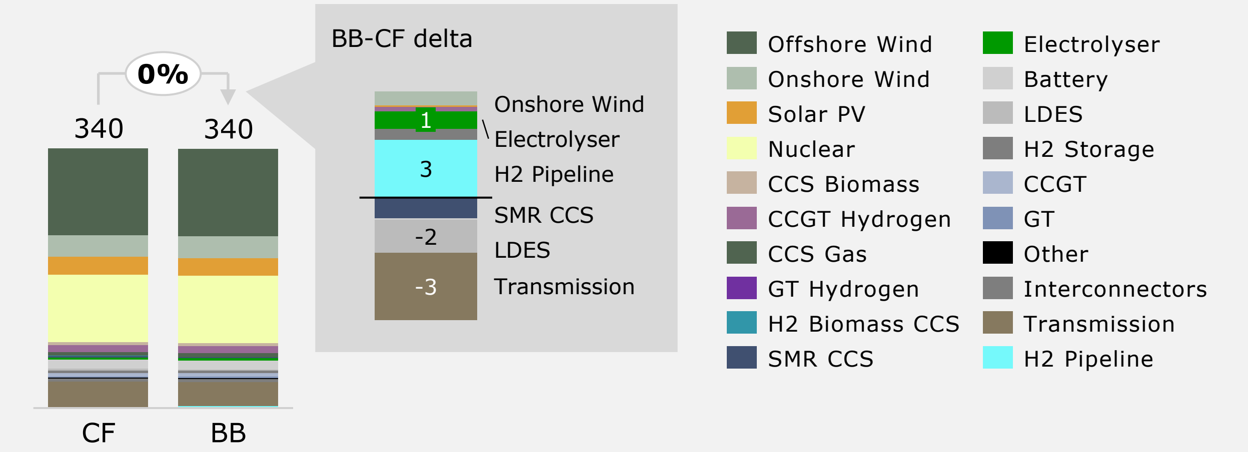
## ANNUAL CAPEX (BN £, REAL 2023)




## COMMENTARY

- The difference in capital expenditure between the two scenarios remains small both in the near term (early 2030s) and over the long term.
- As the backbone infrastructure expands in the late 2030s in the Backbone case, the development of electricity transmission and LDES drops, putting downward pressure on CAPEX compared to the Counterfactual scenario. Conversely, increased CAPEX for electrolysers, hydrogen pipelines, and salt caverns put upward pressure on CAPEX in the Backbone case.

## NPV[1] OF CAPEX BY TECHNOLOGY (BN £, REAL 2023)

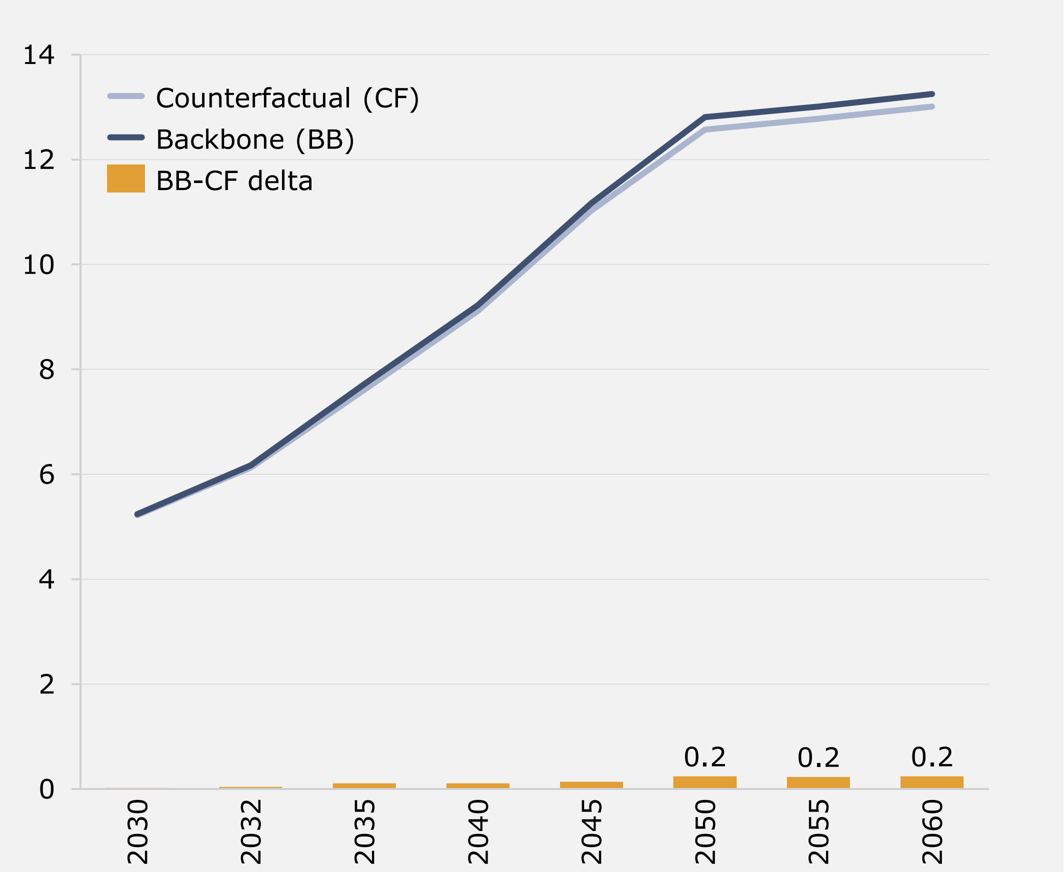



Notes: 1 – NPV is on a 35-year (2025-2060) period using a rate of 3.5% for the first 30 years and 3% for the last 5 years

# Fixed OPEX is marginally higher with a backbone primarily because of the increased electrolyser capacity compared to the Counterfactual case

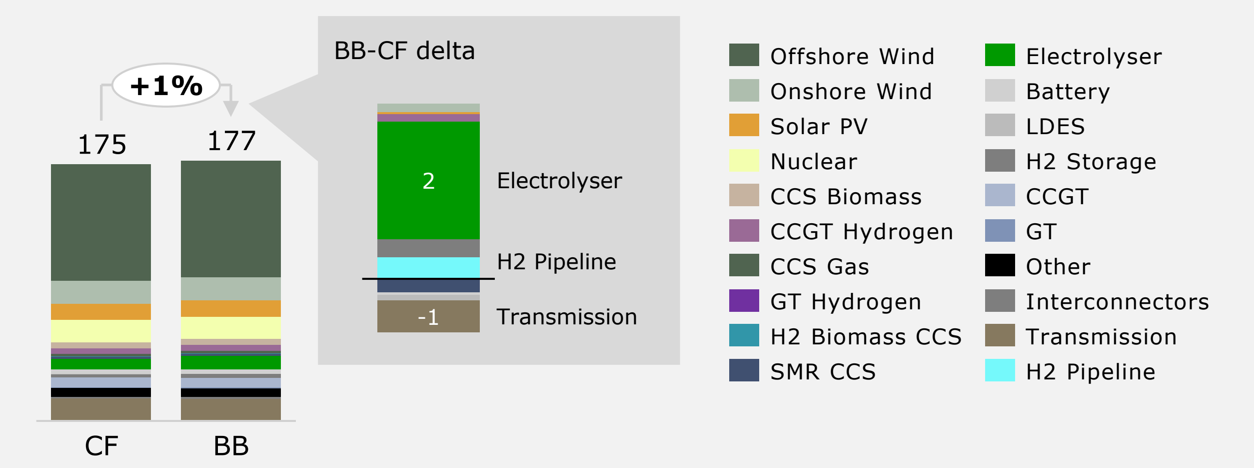
## ANNUAL FIXED OPEX (BN £, REAL 2023)




## COMMENTARY

- Fixed and variable OPEX refer to two different ongoing costs associated with running assets. Fixed OPEX are costs that do not change with the amount of electricity or hydrogen produced or transported, so are incurred regardless of utilisation levels.
- Fixed OPEX is marginally higher in the Backbone case in the long term, with overall very small variation between the two cases. This difference is primarily driven by higher electrolyser costs in the Backbone case compared to the Counterfactual.

## NPV[1] FIXED OPEX BY TECHNOLOGY (BN £, REAL 2023)




Notes: 1 – NPV is on a 35-year (2025-2060) period using a rate of 3.5% for the first 30 years and 3% for the last 5 years

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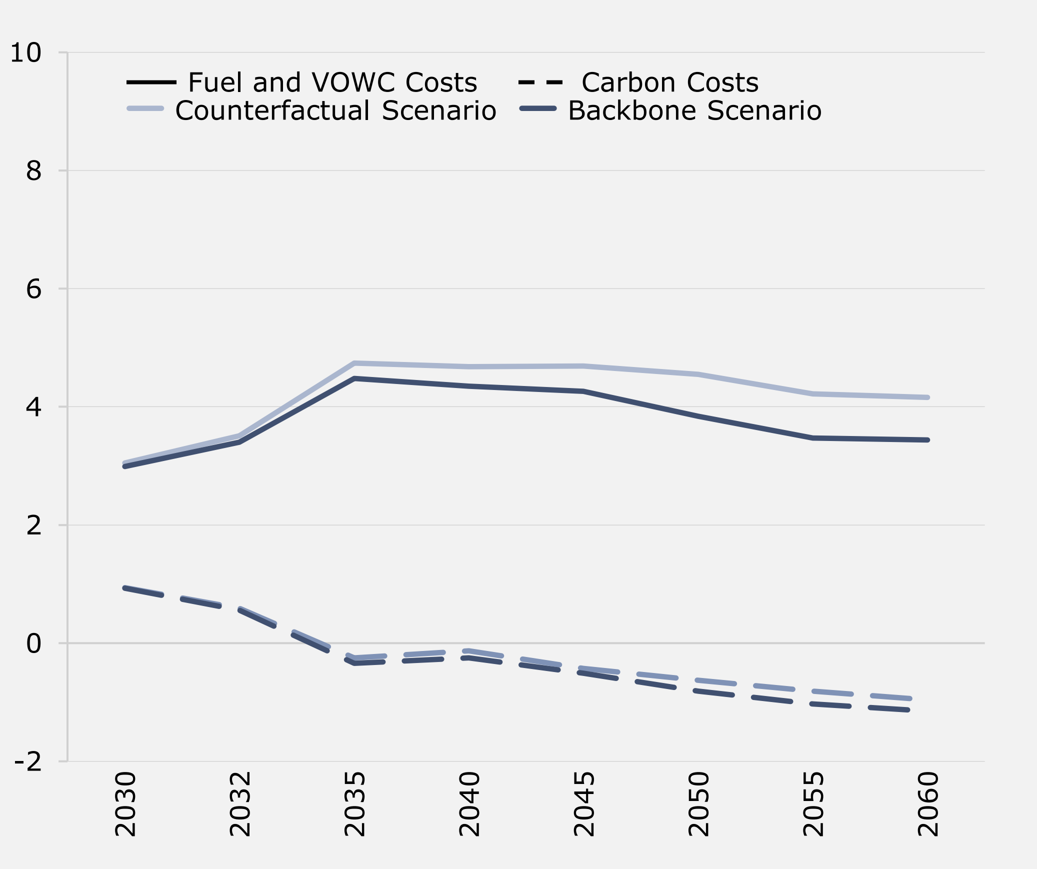
# In the long term, variable OPEX is slightly lower with a backbone, reflecting the move away from SMR-CCS

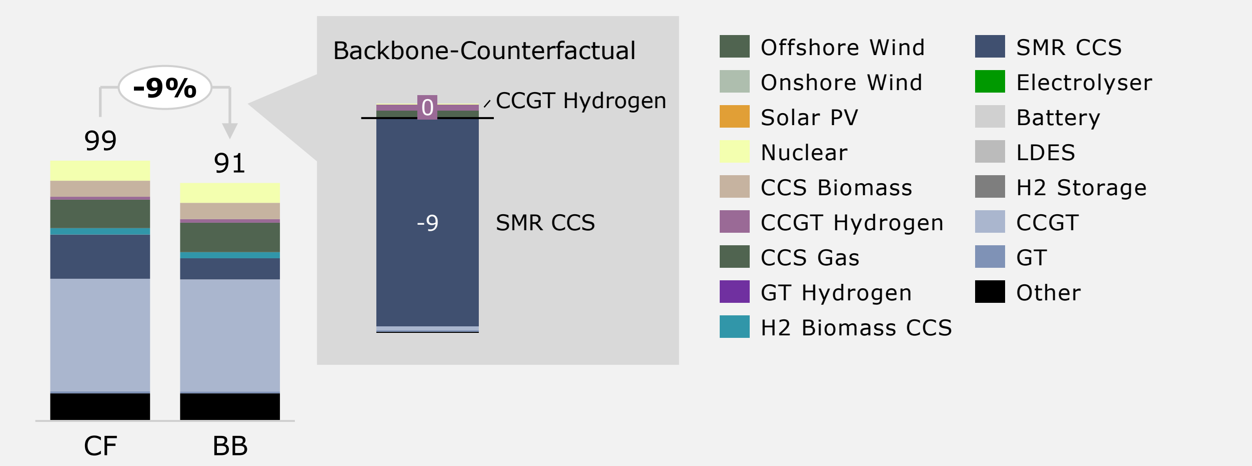
## ANNUAL VARIABLE OPEX (BN £, REAL 2023)




## COMMENTARY

- Variable OPEX can be disaggregated into two key components: 1) fuel and variable other works costs (VOWC)[2], and 2) carbon costs, both of which vary throughout the year, depending on operation of the asset in question.
- The introduction of a backbone marginally decreases the total variable OPEX of the system as the system becomes less dependent on SMR-CCS, and CCGT $H_2$ can run instead, with lower variable costs reflecting the lower cost of green hydrogen used
- Note: The variable cost of carbon turns negative in the early 2030s, reflecting the move to negative emissions in both Base cases around this time.

## NPV[1] VARIABLE OPEX BY TECHNOLOGY (BN £, REAL 2023)




Notes: 1 – NPV is on a 35-year (2025-2060) period using a rate of 3.5% for the first 30 years and 3% for the last 5 years. 2 - VOWC is used in BID3 to describe costs other than fuel and carbon incurred by generators on a per MWh basis.

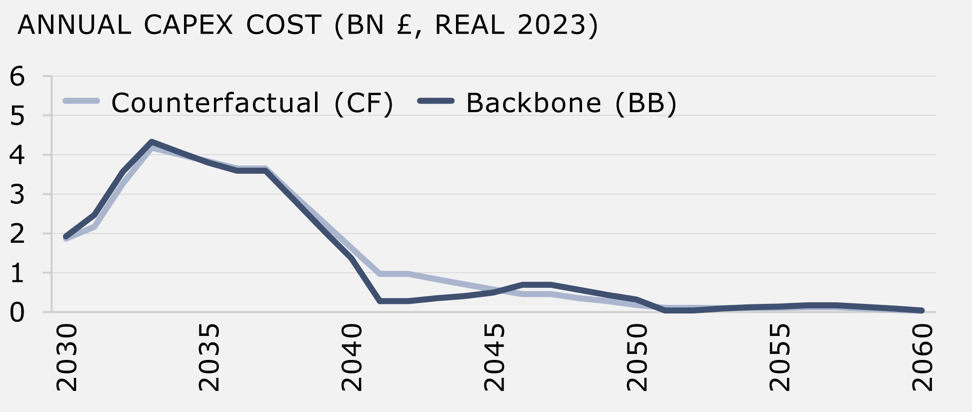
AFRY

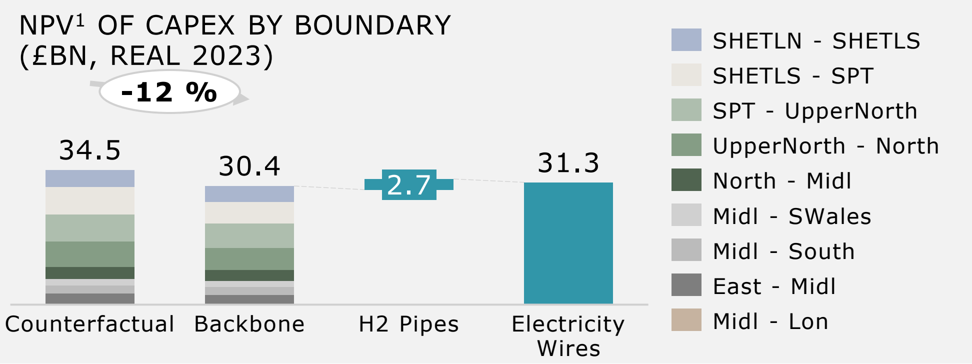
# The Backbone case has a lower CAPEX for infrastructure (i.e., pipeline & transmission costs) compared to the Counterfactual case

## KEY MESSAGES

| | |
|---|---|
| **1** | Introducing the hydrogen backbone leads to a 12% reduction in CAPEX NPV for infrastructure deployment. This reduction occurs because CAPEX savings on new transmission capacity build are greater than the CAPEX expenditure on introducing the hydrogen backbone. |
| **2** | In both cases, the majority of CAPEX investment is expected to take place during the 2030s, with significant capacity deployment anticipated by the end of that decade. |
| **3** | The addition of the hydrogen backbone had minimal impact on the distribution of CAPEX and OPEX across the zones. Since its total cost is relatively small compared to electricity transmission, it does not significantly alter the distribution of the transmission system or the regional distribution of infrastructure costs. |
| **4** | Results are highly sensitive to cost assumptions. When pipeline CAPEX is increased to align with the higher end of estimates reported in the literature, total pipeline costs (CAPEX + OPEX) rise by approximately 3.5× relative to our Base case, which is based on lower-bound assumptions. |

## INFRASTRUCTURE CAPEX COMPARISON



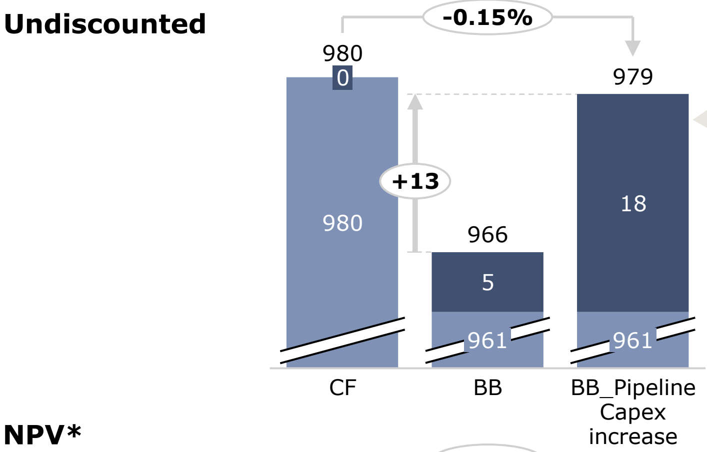

Note: 1 - For this slide, infrastructure refers to hydrogen pipelines and electricity transmission between price areas. NPV is on a 35-year (2025-2060) period using a rate of 3.5% for the first 30 years and 3% for the last 5 years

# Raising backbone CAPEX to a high-end literature estimate erodes base case benefits, turning the NPV into a marginal net loss

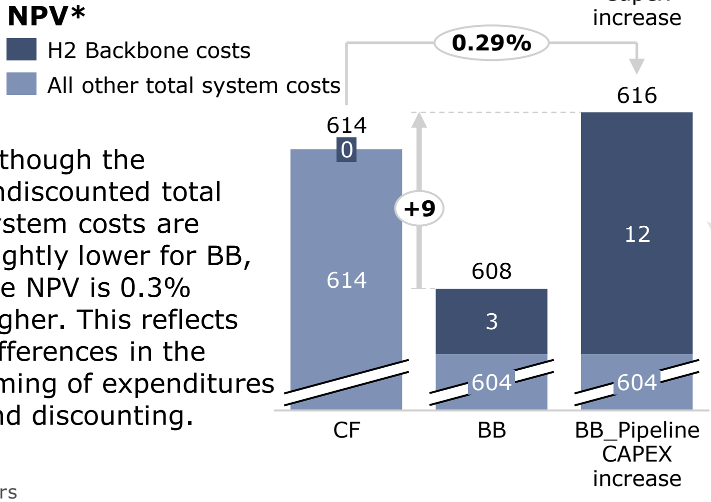
## BACKBONE COMMERCIAL ASSUMPTIONS

| | Base case assumption | Source | Backbone cost assumption change |
|---|---|---|---|
| **Pipeline CAPEX** | **0.53 £/kW/km** | This closely aligns with the European Hydrogen Backbone (EHB) high CAPEX coefficient from the 2022 report when converted using a 75% LF – 2.8 €/kg/1000 km and inflated to real 2023 – no learning rate applied. | Pipeline CAPEX factor increased to just over **£2/kW/km** to match Arup (2023, NIC & Ofgem) assumption of ~£12 bn transmission pipeline costs |
| **Pipeline fixed OPEX** | 0.0033 £/kW/km/year | Based on CCC study - no variable OPEX | **No change** |
| **Compressors Capex** | = Pipeline CAPEX * ~1.4 | Based on EHB CAPEX relationships | **No change** |
| **Compressor OPEX** | 1.7% of compressor capex values (Units are £/Year) | Based directly on the EHB | **No change** |

## TOTAL SYSTEM COST BY TECHNOLOGY (BN £, REAL 2023)




By increasing $H_2$ pipeline CAPEX from just over £3 bn to £12 bn (undiscounted). Total system costs for the backbone including compressors and OPEX, increased from **£5 bn to £18 bn**.




Although the undiscounted total system costs are slightly lower for BB, the NPV is 0.3% higher. This reflects differences in the timing of expenditures and discounting.

The NPV increase caused by increasing the cost of the Backbone results in an **£~9 Bn** increase in total system costs NPV, eroding the BB marginal benefits

Notes: CF – Counterfactual scenario, BB – Backbone scenario.
* NPV is on a 35-year (2025-2060) period using a rate of 3.5% for the first 30 years and 3% for the last 5 years

# Contents



# AFRY identified a set of potential non-commercial benefits/indicators to help appraise the additional system-wide benefits of a hydrogen backbone

| CONTEXT | OBJECTIVES | APPROACH |
|---|---|---|
| – The non-commercial benefits assessment captures the broader strategic, social, and environmental value of the hydrogen backbone that is not reflected in traditional costing analysis—helping to inform more holistic decision making. | – **Identification of benefits:** A list of potential non-commercial benefits have been shortlisted<br>– **Quantification and monetisation:** The report assesses and quantifies the identified non-commercial benefits, including benefits measured in physical units (e.g. GWh of avoided curtailment, tonnes of $CO_2$ avoided and jobs created) and, where appropriate, monetises these impacts using recognised valuation approaches. | – Literature review to establish a long list of indicators<br>– Thematic categorisation of benefits<br>– Filtering for Quantifiability & Relevance<br>– Preliminary list |

**In Part 1, the non-commercial benefits and risks associated with the hydrogen backbone were quantified for the Base Case scenarios. This assessment has been extended in Part 2, where the non-commercial benefits are also quantified for the sensitivity scenarios where applicable.**

**BB vs CF**

- Green – Positive impact
- Amber – No material impact
- Red – CF is better

# The backbone increases $CO_2$ savings, cuts curtailment, increases green hydrogen, and reduces gas reliance which strengthens resilience

| | Type | Definitions | Result Highlights (Backbone vs Counterfactual)[1] | Impact |
|---|---|---|---|---|
| Environmental & Climate | **Societal $CO_2$ Cost Savings** | – NPV of Societal $CO_2$ Cost Savings (Net of ETS) | – £920 Mn in savings[2] | Green |
| Environmental & Climate | **Risk of Water Stress** | – Pressure on water resources from green hydrogen production[3] | 1. <1% of current average GB water supply per year<br>2. May be a material impact in particular regions, needs further analysis (see annex) | 1: Amber; 2: Red |
| System Integration | **Integration of Renewable Electricity** | – Impact on RES curtailment | – Total of ~520 TWh of curtailment savings[2]<br>– ~15 TWH per year annual avg.[2] | Green |
| System Integration | **Integration of Green & Blue Hydrogen** | – Impact on green and blue hydrogen production | – 167 TWh of more $H_2$ production[2]<br>– 82% of total 35-year hydrogen production is green vs 60% in the CF | Green |
| Security of Supply | **Diversification** | 1. Proportion of total energy demand met by imports<br>2. Total gas reliance in power and hydrogen<br>3. Diversity index of energy sources | 1. 183 TWh of more power imports[2]<br>2. ~ 644 TWh of gas use savings[2]<br>3. No difference between the two scenarios | 1: Red; 2: Green; 3: Amber |
| Security of Supply | **Resilience** | System impacts due to:<br>1. Gas price shock for select year (2055)<br>2. Frequency & magnitude of lost load in low wind weather year | 1. £2.6 bn saving in shock year 2055<br>2. No loss of load in both scenarios in any year | 1: Green; 2: Amber |

Note: 1-All values refer to the Backbone as compared to the Counterfactual 2 – over the modelled period of 2025-2060 (35 years) 3-does not include water needs for any other hydrogen production process such as SMR or Gasification

**BB vs CF**

- Green – Positive impact
- Amber – No material impact
- Red – CF is better



# The backbone has marginal impact on GVA’s and Employment, however the indications are that it would improve industrial competitiveness

| | Type | Definitions | Result Highlights (Backbone vs Counterfactual) | Impact |
|---|---|---|---|---|
| Economy, Employment & Skills | **Gross Value Added (GVA)** | – Used to measure the contribution of the backbone to the overall economy. As a measure of economic output or benefit | – ~£5 bn less Gross Value Added (GVA) (<1% of total GVA)<br>– Regionally, the BB scenario shifts GVA towards Shetl North, Midlands, and East, at the expense of regions sandwiched in between | Amber |
| | **Employment Impacts** | – Estimates the employment impact (full-time equivalent (FTE) job years) due to domestic GB investment | – ~1,000 fewer full-time equivalent (FTE) job years<br>– ~3100 FTE Job years per year over the 35 years<br>– More FTE Job Years in England and less in Scotland and Wales | Amber |
| | **Industrial Competitiveness** | – Improved industrial competitiveness arising from reduced hydrogen cost in industry | Hydrogen consumers will save ~ £4 Bn (2040-2060) due to lower hydrogen prices increasing competitiveness | Green |

Note: Note on FTE Job years - “1,000 FTE job years” represents the equivalent of 1,000 full-time jobs sustained for one year - One FTE job year equals one person working full-time for one year (≈2,000 hours). All values refer to the Backbone as compared to the Counterfactual



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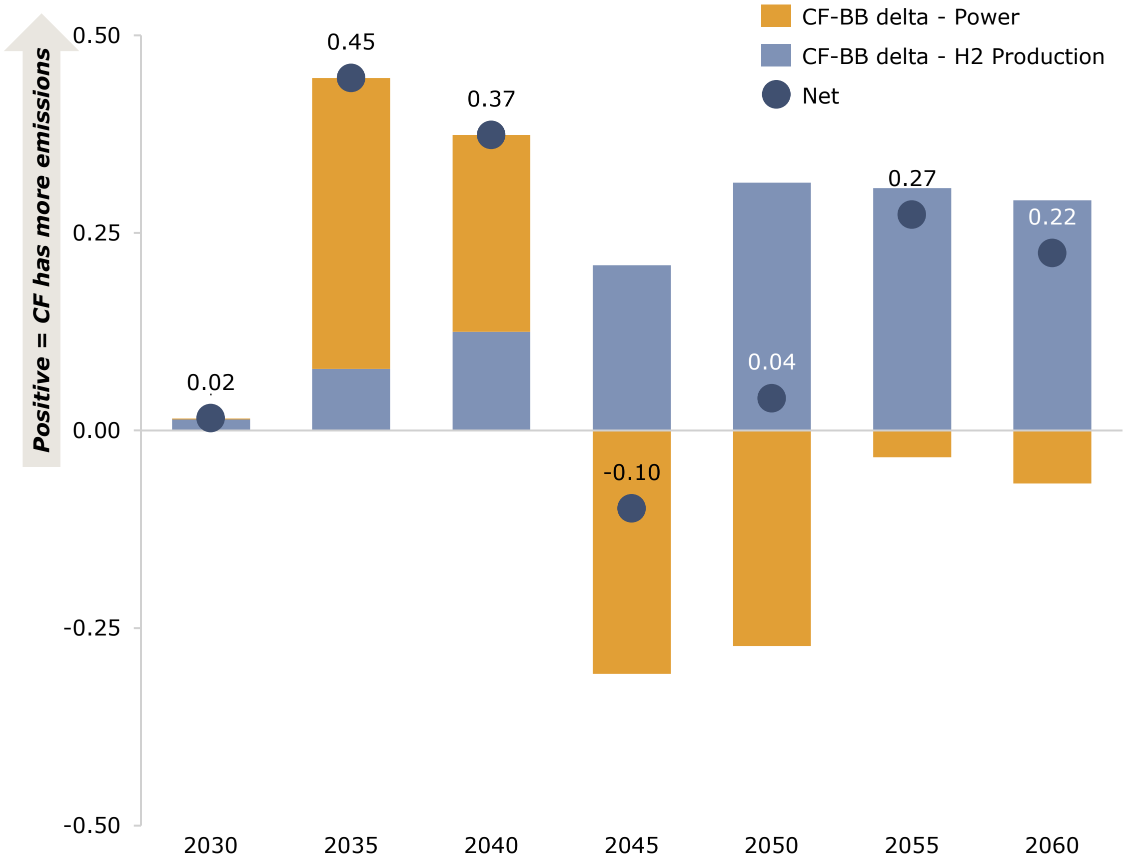
PART 1 | NON-COMMERCIAL BENEFITS - $CO_2$ EMISSION VARIATIONS

# Adding the backbone lowers renewable curtailment and reduces reliance on SMR with CCS, leading to lower emissions over most of the modelled period

## TOTAL NATIONAL EMISSIONS Δ, MTCO2




## COMMENTS

- The charts show the difference in emissions in $mtCO_2$ from the power and hydrogen sectors between the Backbone and Counterfactual cases across GB.
- **Variation between cases:** Adding the backbone reduces renewable (zero emission) curtailment levels and results in less build of SMR with CCS, which causes a decrease in emissions across most of the modelled period.
- **In the hydrogen sector:** The backbone has an absolute advantage as it enables much more electrolysis build.
- **Policy compliance:** both the Counterfactual and Backbone cases are designed to meet government decarbonisation targets of net zero by 2050.
- **Slightly more emissions in the Backbone scenario in the 2040's:**
  - In some years, emissions are slightly higher in the Backbone scenario due to transmission constraints between zones.
  - Limited transfer capacity forces certain zones to rely temporarily on local CCGT generation to maintain reliability.
  - This short-term rise reflects transitional system tightness; continued RES expansion beyond 2055 alleviates these constraints and restores the Backbone scenario's emissions advantage.

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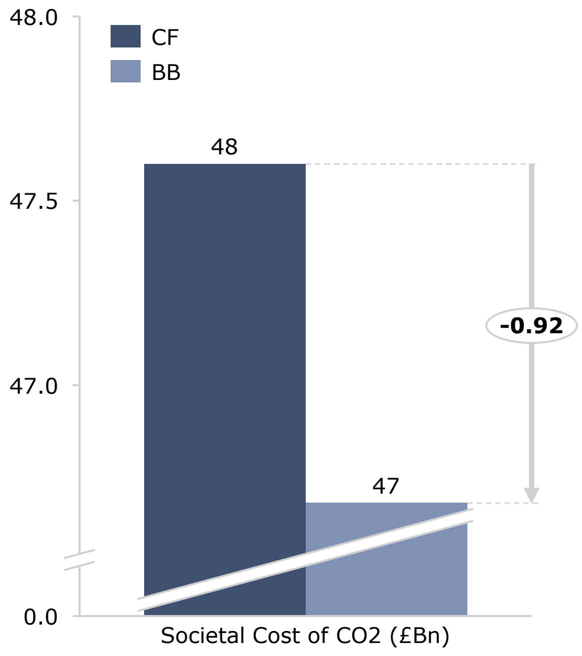
PART 1 | NON-COMMERCIAL BENEFITS - $CO_2$ EMISSION VARIATIONS

# The Backbone delivers just under £1Bn (NPV) in benefits, meaning society avoids ~£1Bn in residual $CO_2$ costs compared to the Counterfactual

## NPV OF TOTAL NATIONAL SOCIETAL BENEFITS £ BN - REAL 2023




$NPV\ [CO2variation * (Societal\ cost\ of\ CO2 - ETS\ CO2\ price)] =$ **£920m**

## NPV OF RESIDUAL SOCIETAL CARBON VALUE

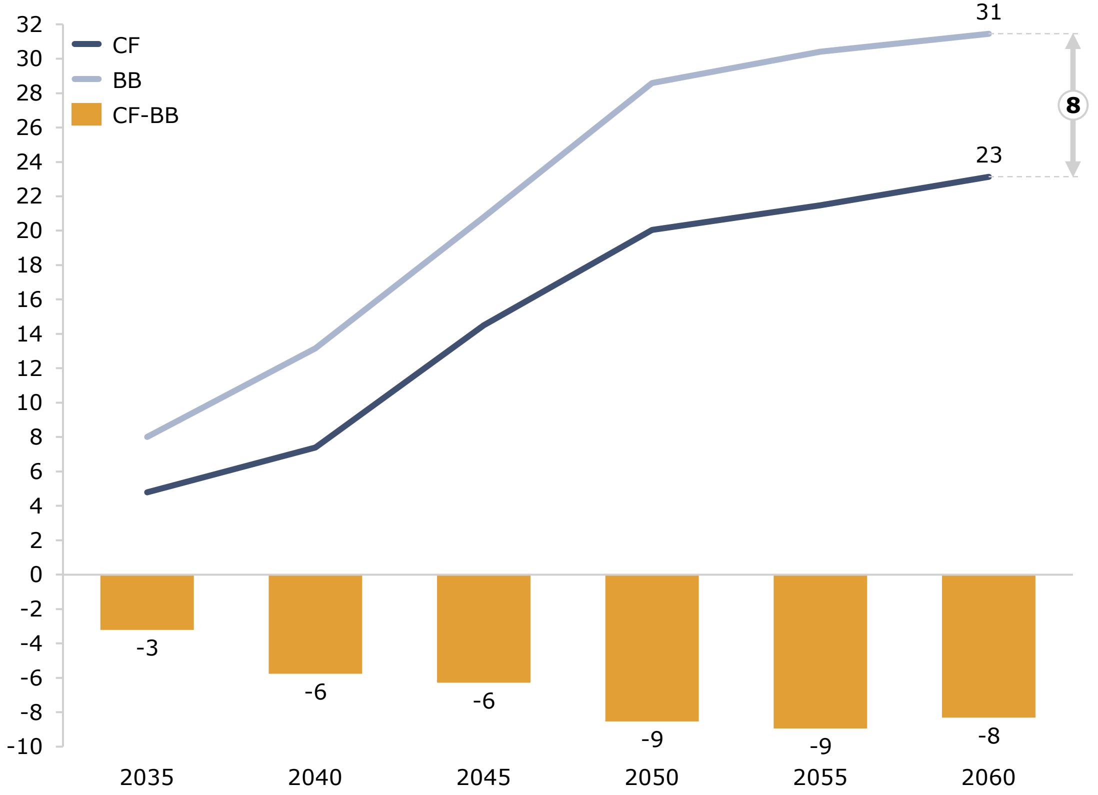
- ***£920m*** *NPV of emission savings in the Backbone vs Counterfactual*
- **Carbon values used:** Central series from BEIS/Green Book guidance (Valuation of Greenhouse Gas Emissions for Policy Appraisal), converted to real 2023 £.
- **Avoiding double counting:** The UK ETS price is subtracted from the BEIS carbon value → this represents the "unpriced" societal cost not already captured by market trading.
- The production of blue hydrogen in the UK is subject to the UK Emissions Trading Scheme (UK ETS) according to Schedule 2 (Regulated activities), UK ETS Order 2020 (SI 2020/1265).
- Facilities involved in hydrogen production, as well as the associated Carbon Capture, Utilisation, and Storage (CCUS) infrastructure, fall under the scope of the scheme. As such to prevent double counting the ETS price is also subtracted when applied to emissions from hydrogen generation.
- UK ETS offers free allocation to certain installations.
- For simplicity and given the uncertainty surrounding the phase-out of free allowances under the UK ETS, this study assumes that no free allocations are applied.

Note: NPV is on a 35-year (2025-2060) period using a rate of 3.5% for the first 30 years and 3% for the last 5 years
Source: Valuation of greenhouse gas emissions: for policy appraisal and evaluation Published 2 September 2021

PART 1 | NON-COMMERCIAL BENEFITS - WATER STRESS

# Water use for green $H_2$ production in the Backbone case is negligible (<1% per year) compared to the national annual average water supply in GB

## WATER CONSUMPTION FOR ELECTROLYTIC $H_2$ PRODUCTION IN GB (MILLION M³)




## COMMENTS

- The chart shows the capacity delta between the Counterfactual and the Backbone cases for water use for green hydrogen production in GB.
- The Backbone case allows for more electrolysis and thus more consumption of of water
- Electrolytic hydrogen uses <1% per year of GB's total average water supply per year:
  - The average GB supply through distributed networks are ~5,900 million m³ per year
  - Average historical water consumption (2019–2023) was derived from annual data published by regional water companies and averaged to ~5,900 million m³ per year.
  - This figure represent total water put into supply – domestic, non-household, and leakage.
  - Minor differences in regional coverage and reporting methodologies between companies were recognised as caveats and potential sources of uncertainty.
- Values reflect annual averages, not seasonal or peak demand. Also Note that climate-related changes in water availability have not been considered as part of this study.

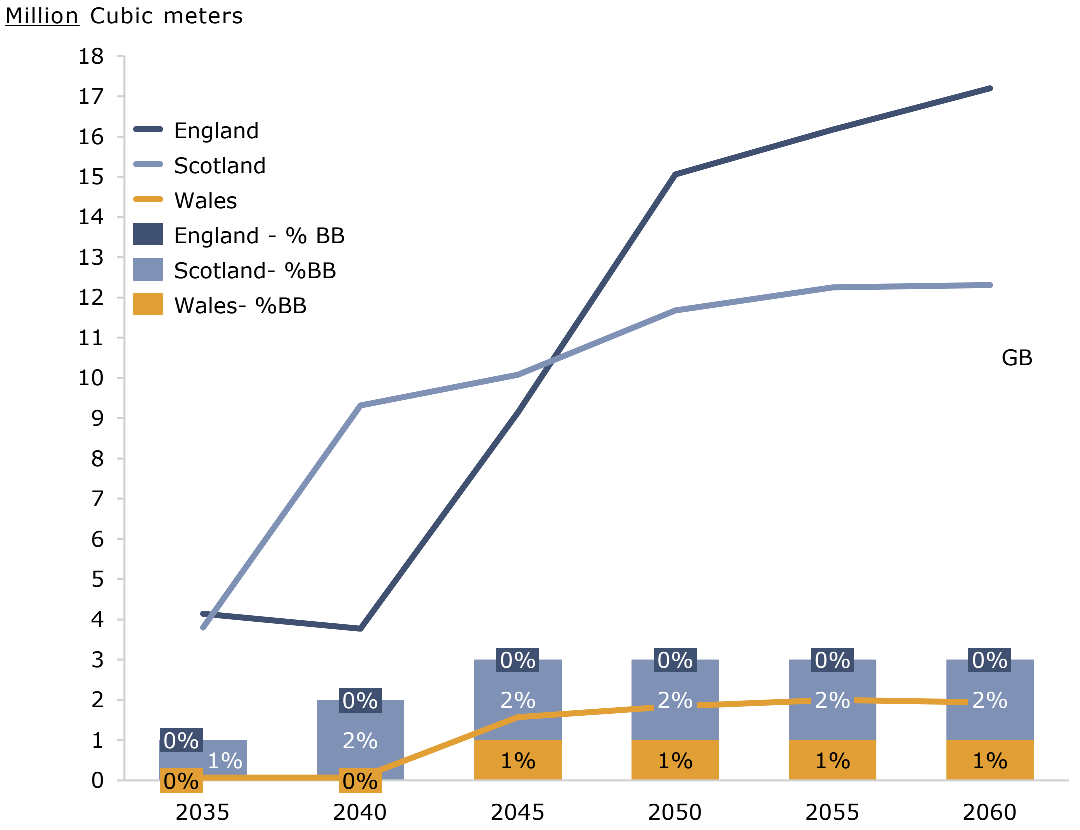
Note: Analysis based on national annual averages; peak or seasonal supply–demand variations not assessed.
Water consumption derived from the projected $H_2$ output (TWh) based on LHV and the stoichiometric ratio of 9 kg of water required per kg of H2 produced through electrolysis. In practice, actual water use will be almost double due to purification and process requirements(cooling), however these have not been considered and only water for conversion has been considered, source: Environment Agency, Environmental capacity for industrial clusters - Humber pathfinder project April 2022 .

PART 1 | NON-COMMERCIAL BENEFITS - WATER STRESS

# The largest increase in annual demand is seen in Scotland, but this is still only 2% per year of Scotland's annual average water supply

## ELECTROLYSER WATER CONSUMPTION AND SHARE OF NATIONAL WATER USE (MILLION M³, %) - BACKBONE




## COMMENTS

- The chart illustrates projected water demand for electrolysis (2035–2060), broken down into Scotland, England, and Wales.
- Breaking down the impact at a country level reveals some asymmetry—Scotland and Wales show modest usage relative to public water supply (around 2% and 1% respectively), while England's contribution remains negligible.
- At a GB-wide scale, overall water use from electrolysis remains immaterial.
- That said, more location-specific analysis may be required to assess potential localised water stress, particularly in areas where electrolysers are sited in constrained water areas.

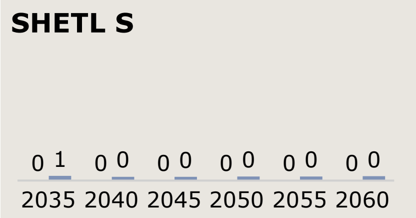
Note: Analysis is based on national annual averages; peak or seasonal supply–demand variations not assessed. England national annual average water distributed water supply: 5094 million m3/year, Scotland: 547 m3/year, Wales 246 m3/year
Water supply figures represent public distribution only and exclude direct abstractions by power generation, agriculture, and industry.

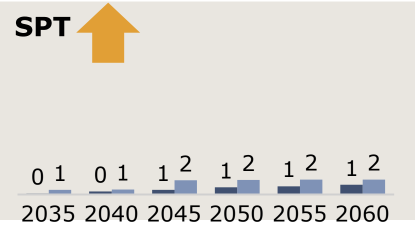
 

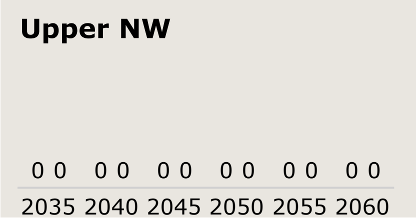
PART 1 | NON-COMMERCIAL BENEFITS - WATER STRESS

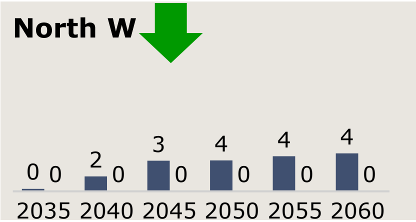
# Electrolyser expansion in water-stressed areas such as Shetl-N and South Wales may strain local water resources

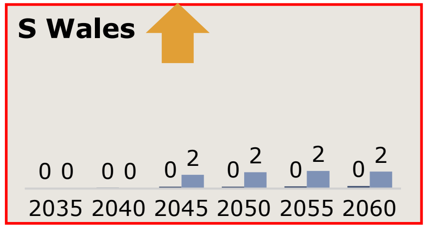
## WATER CONSUMPTION FOR ELECTROLYTIC HYDROGEN PRODUCTION (MILLION M³)



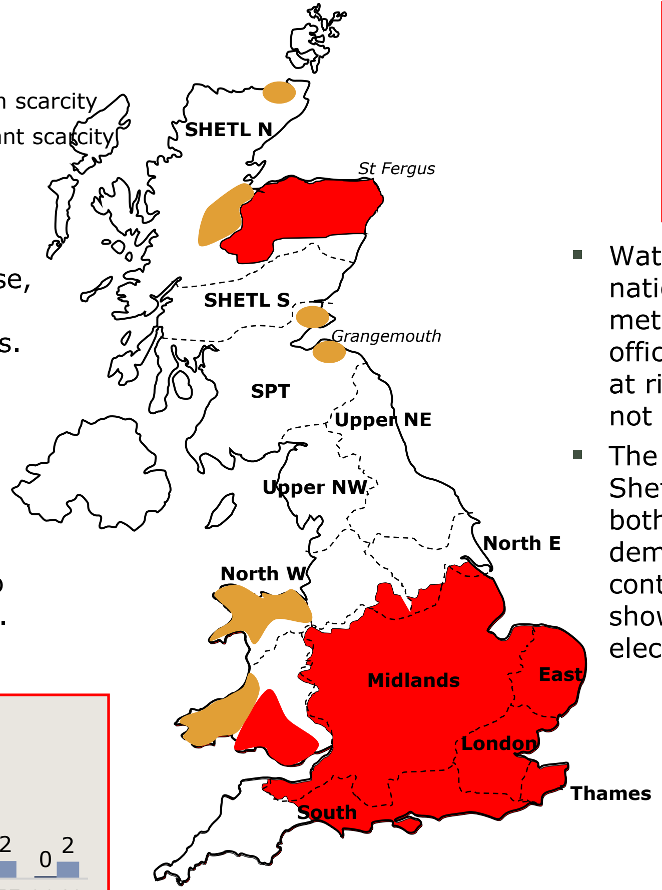



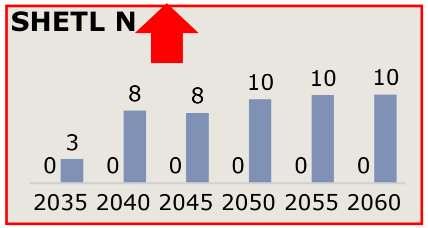



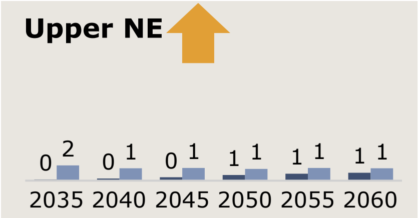

CF
BB

Area of moderate to high scarcity
Area of Serious/Significant scarcity

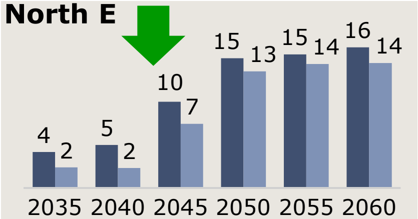
- In the backbone case, overall hydrogen production increases.
- A larger share is produced via electrolysis.
- Geographically, production shifts, relocating from northern England to Scotland and Wales.

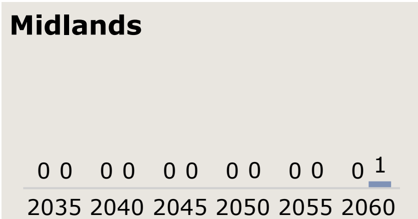


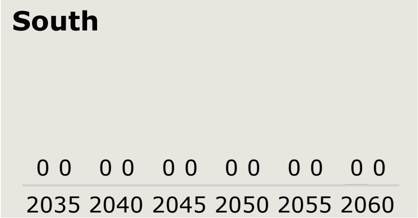



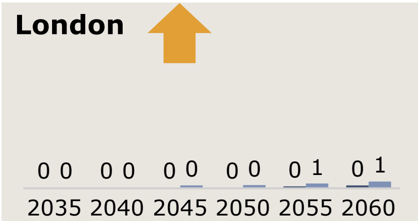




- Water stress levels are based on national assessments. While methodologies vary, regions officially designated as stressed or at risk are accepted as given and not normalised.
- The key areas of concern are Shetl-N and South Wales, where both water scarcity and electrolytic demand are significant. In contrast, England's at-risk areas show no material increase in electrolysis-related consumption.



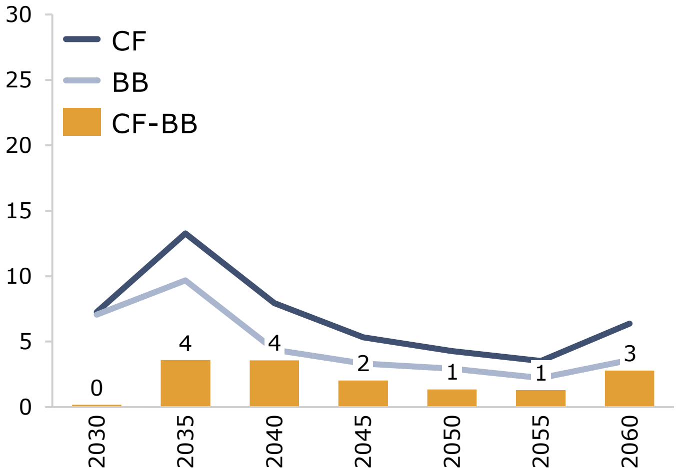




Environment Agency (2021). Determination of water stressed areas in England: consultation, Scottish Environment Protection Agency (SEPA) (2025). Water scarcity report – 25 Sep. Natural Resources Wales (NRW). *Dry Weather and Drought Updates (2025). ŵr Cymru Welsh Water (2019-2023). Annual Performance Report. Note: according to the Environment Agency South Humber Bank has reached its water abstraction limit, with no new permits available due to climate constraints. It appears under 'Midlands' on the map above.*

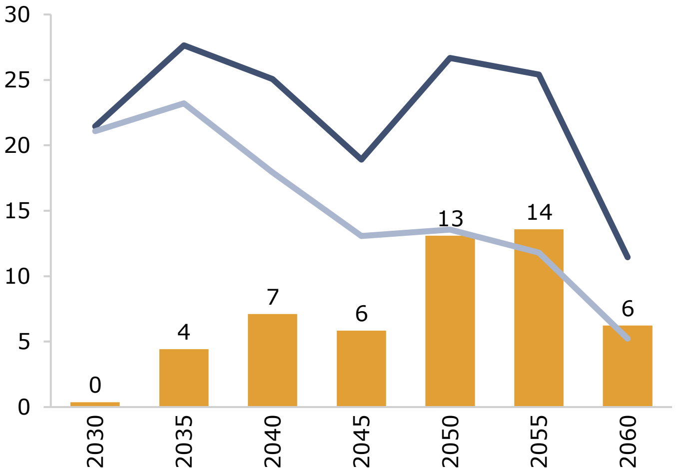
PART 1 | NON-COMMERCIAL BENEFITS - INTEGRATION OF RENEWABLE ELECTRICITY

# From 2025 to 2060 the Backbone case would have a total of ~520 TWh of curtailment savings compared to the Counterfactual

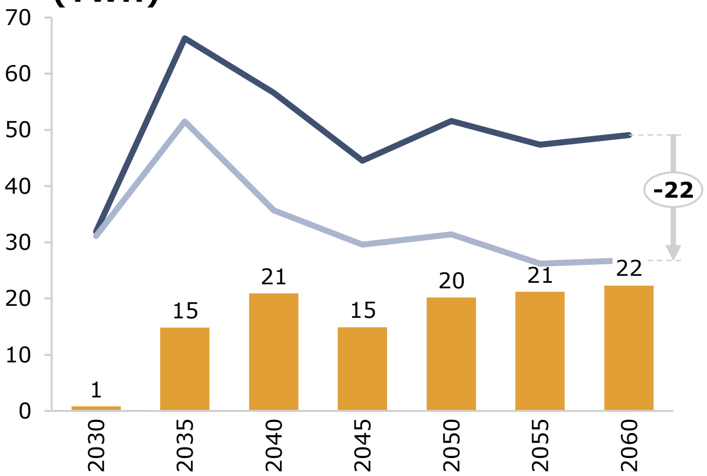
**OFFSHORE WIND CURTAILMENT (%)**




**ONSHORE WIND CURTAILMENT (%)**




**TOTAL RES (WIND/SOLAR) CURTAILMENT (TWH)**




- The charts show the curtailment levels by resource of offshore wind, onshore wind, GB for the Backbone and Counterfactual scenarios.
  - **Curtailment Reduction:** Over a 35-year period, the Backbone scenario delivers a total curtailment saving of approximately 520 TWh compared to the counterfactual
  - The backbone curtailment would be ~6% of total (2025-2060) RES (Wind/Solar) generation before curtailment, whereas in the Counterfactual case it would be 8%
  - **Drivers for reduced curtailment:** With a backbone, a higher proportion of excess renewable generation can be converted to hydrogen via electrolysis for transportation to other zones with greater hydrogen demand and / or storage potential. Without the pipeline more of this excess power is curtailed

Note % Curtailment = Curtailed Energy /(Curtailed Energy + Generated Energy)



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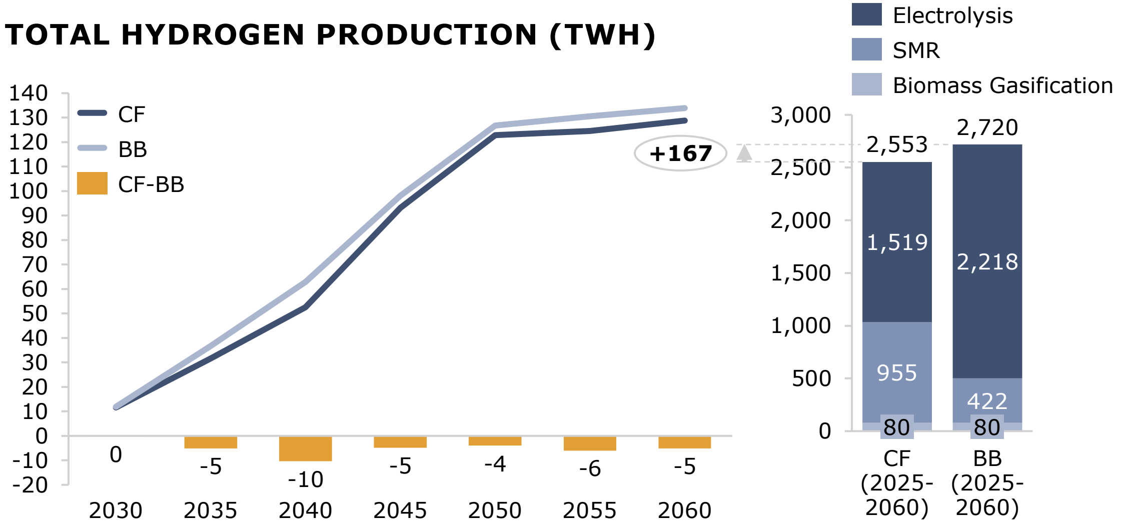
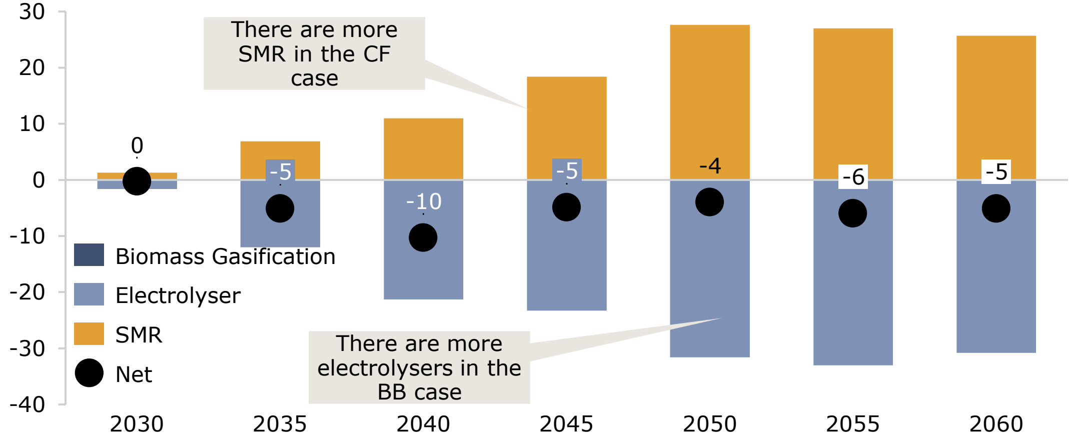
PART 1 | NON-COMMERCIAL BENEFITS - INTEGRATION OF GREEN & BLUE HYDROGEN

# The backbone enables an additional 167 TWh of domestic production of hydrogen of which 82% is green

## TOTAL HYDROGEN PRODUCTION (TWH)




## TOTAL HYDROGEN PRODUCTION DELTA (CF-BB) (TWH)




- The charts show total hydrogen production alongside means of production.
- The Backbone produces 167 TWH more of Hydrogen compared to the Counterfactual (Sum 2025-2060) and 82% of production ends up as green hydrogen compared to 60% in the Counterfactual
  - **Electrolyser capacity:** A backbone enables more electrolyser capacity overall across GB Counterfactual. This is because electrolysers are able to locate in zones with higher renewable potential, with the hydrogen produced able to travel down the pipelines to the zones with high hydrogen demand
  - **SMRs:** A backbone significantly reduces the build of additional SMRs, as it will be cheaper to build electrolysers and transport the produced hydrogen, rather than building SMRs which use relatively expensive gas, and struggle to compete. A very small amount of SMRs remain in the Midlands, South and South Wales to meet residual hydrogen demand after accounting for imports and exports.



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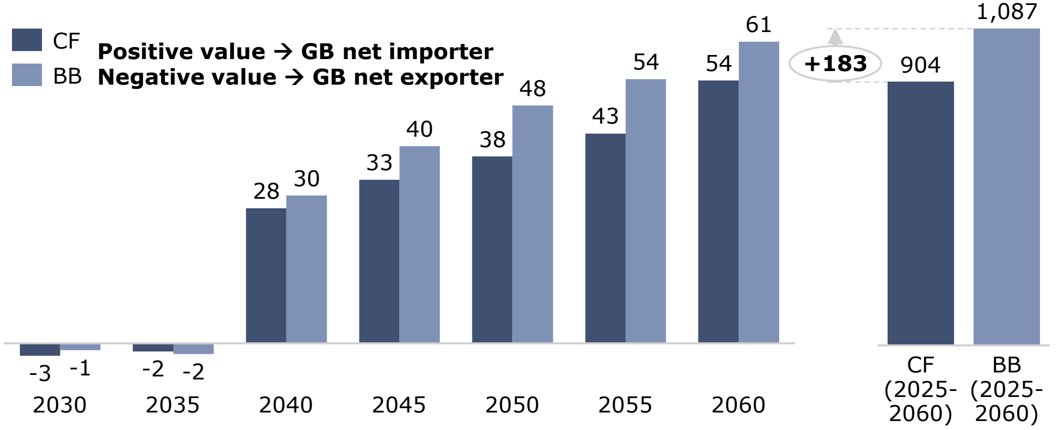
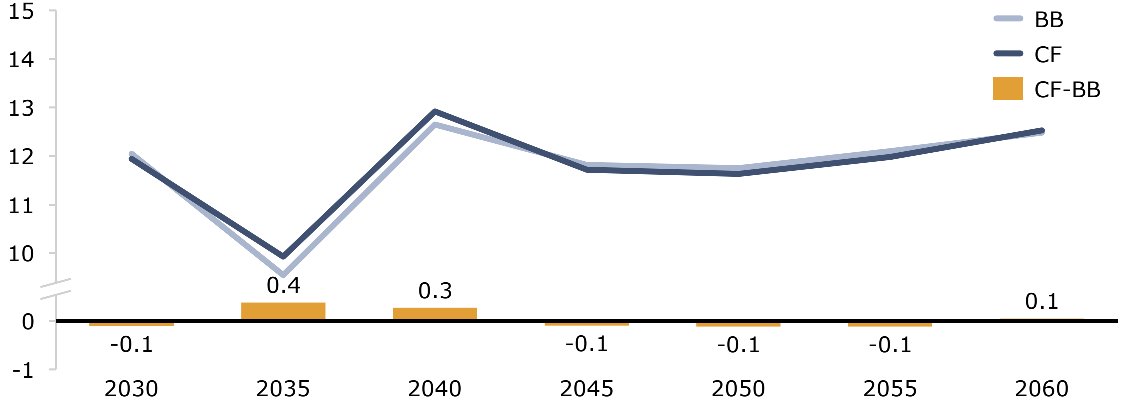
# The Backbone scenario relies more on power imports compared to the counterfactual

## NET FLOWS FROM INTERCONNECTORS (TWH)




## IMPORTS AS % OF GB TOTAL DEMAND INCLUDING ELECTROLYSIS



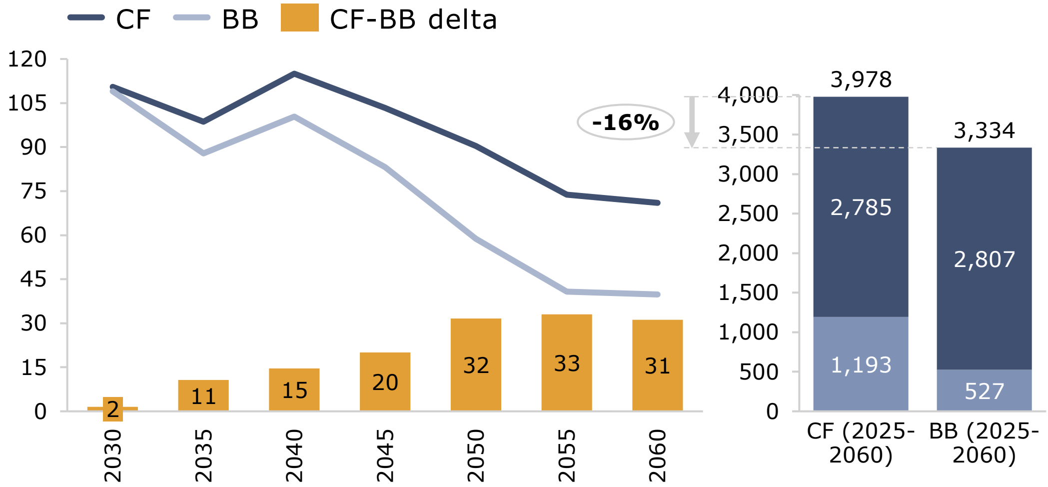

- The chart on the left shows that by 2040 GB consistently imports more in the Backbone scenario.
- Over the course of the modelled period the Backbone scenario imports 183 TWh more power than the Counterfactual.
- Imports as a share of total demand (including electrolysis) are nearly identical across the Counterfactual and Backbone scenarios.
- This indicates that the backbone does not materially change the system's reliance on imports.
- The Backbone scenario includes significantly higher electricity demand from electrolysis.
- The balance between domestic generation and external supply remains essentially the same in both cases.
- Electrolysers in the Backbone case provide flexibility but also absorb cheap power.
- That can reduce export opportunities — power that would have been exported in the Counterfactual is now consumed domestically for hydrogen.
- Conversely, when renewable output is low, GB may import more to maintain electrolyser demand.

Notes: Interconnector losses have been accounted for in the Net flow calculation

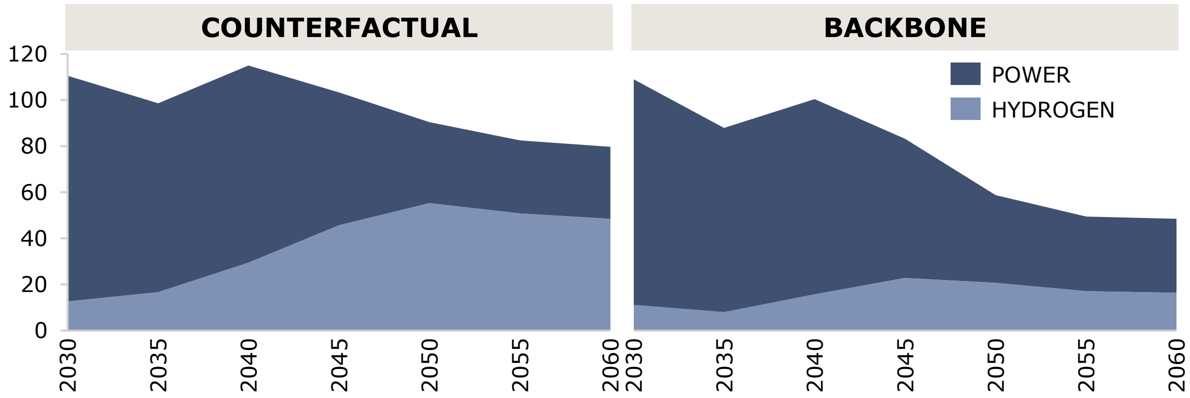
PART 1 | NON-COMMERCIAL BENEFITS - DIVERSIFICATION – GAS RELIANCE

# The Backbone scenario shows a reduced reliance on gas which is mostly mirrored in the $H_2$ sector by a large decrease in blue hydrogen production

## GAS USED TO PRODUCE ELECTRICITY & HYDROGEN (TWH)




## PROPORTION OF GAS USED FOR POWER AND HYDROGEN (TWH)




- There is 644TWh less gas consumed in the BB scenario over the period of the study
- That corresponds to approximately 18 TWh less gas consumption per year in the Backbone scenario
- The reduced reliance on gas can be seen as being a result in the shift from SMR hydrogen production to Electrolytic hydrogen production
- In power there is a slight increase in gas consumption in the Backbone case owing to CCGT's running slightly more compared to the Counterfactual in certain tight years . Refer back to $CO_2$ Emission variations section of the Non-Commercial Benefits section of the report where this is discussed in more detail.

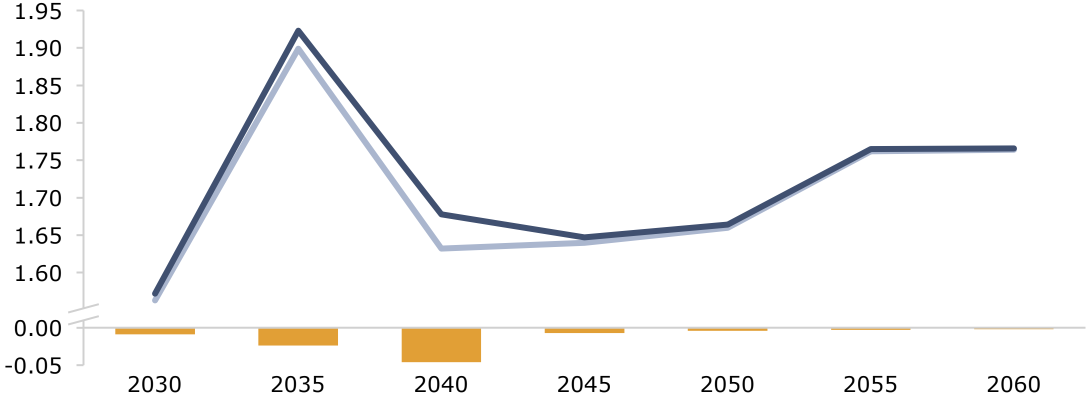
 

PART 1 | NON-COMMERCIAL BENEFITS - DIVERSIFICATION –DIVERSITY INDEX

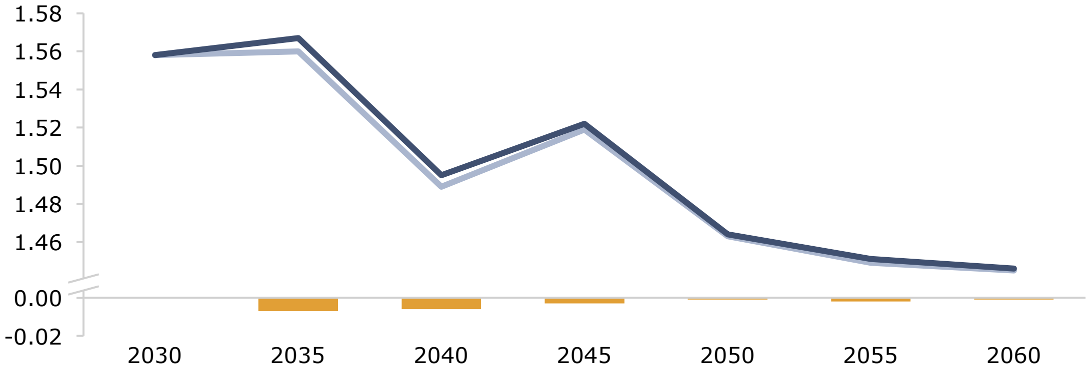
# There is no material difference in fuel diversity between the two scenarios, as broader decarbonisation trends drive convergence in fuel and plant types.

CF BB CF-BB delta

## SHANNON–WIENER DIVERSITY INDEX FOR FUEL USED FOR POWER




## SHANNON–WIENER DIVERSITY INDEX FOR AVAILABLE PLANT CAPACITY




## DESCRIPTION

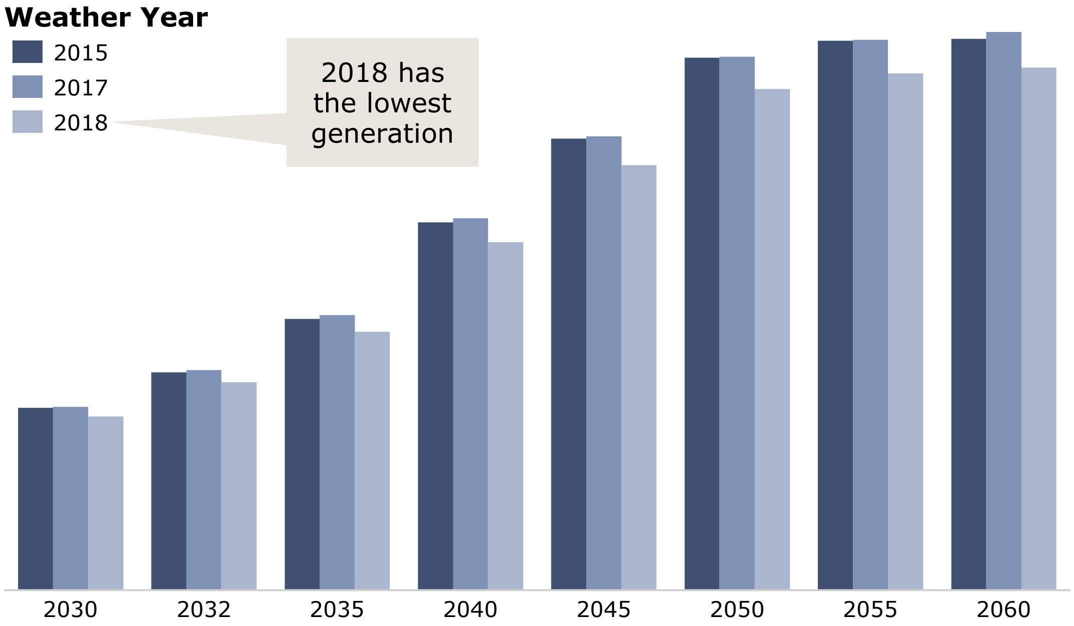
Diversity indices: Shannon-Wiener Index

- $for\ each\ year = Shannon - Wiener\ Index = -\sum^{n} p\,i \cdot ln(p\,i)$
  - $pi$ = Proportion of total energy supply/or capacity from source $i$
  - $pi = \frac{Energy\ from\ source\ i\ (Twh)}{Total\ energy\ supply\ (Twh)}$ or $pi = \frac{Available\ capacity\ plant\ type\ i\ (GW)}{Total\ available\ capacity\ (GW)}$
  - $n$ = Total number of energy sources
  - Higher values = more diverse

- The Index reflects diversity of energy sources (based on fuels used for power generation or available capacity of power plant types), measured in TWh.
- **Backbone vs. Counterfactual**: Minimal difference in energy source diversity or plant type diversity between the two scenarios.
- Both cases rely on similar energy sources and have available plants in comparable proportions, so diversity and evenness remain unchanged.
- The backbone hasn't materially improved resilience through a more diverse mix — its benefit lie elsewhere
- Installed Capacity Trends: As fossil fuels are phased out, fewer technologies (e.g. wind, solar, nuclear) dominate capacity, reducing mix evenness.
- Interpreting a Declining Index: A lower Shannon–Wiener Index in a decarbonising system reflects narrowing generation types (in GW), not reduced security or sustainability. System resilience may improve through flexibility, interconnection, and storage—factors not captured by fuel-based diversity metrics.

# The model builds sufficient capacity in both the Backbone and Counterfactual cases to avoid load loss, even in the low-wind year (2018)

## GB OFFSHORE WIND GENERATION BY WEATHER YEAR (TWH)




- Of the three historic weather years incorporated into the BID3 modelling (2015, 2017, and 2018), 2018 demonstrates the weakest wind conditions, as evidenced by GB offshore wind generation data shown in the chart.

## CONCLUSIONS

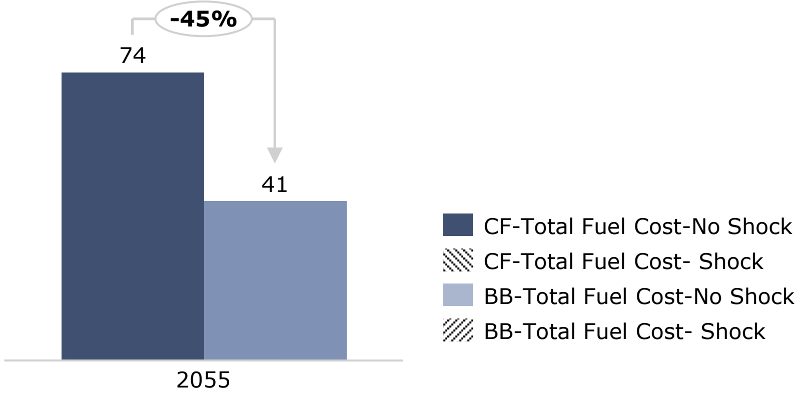
- The standard dispatch analysis shows no difference in the hours of load loss across scenarios, indicating comparable system reliability under both configurations.

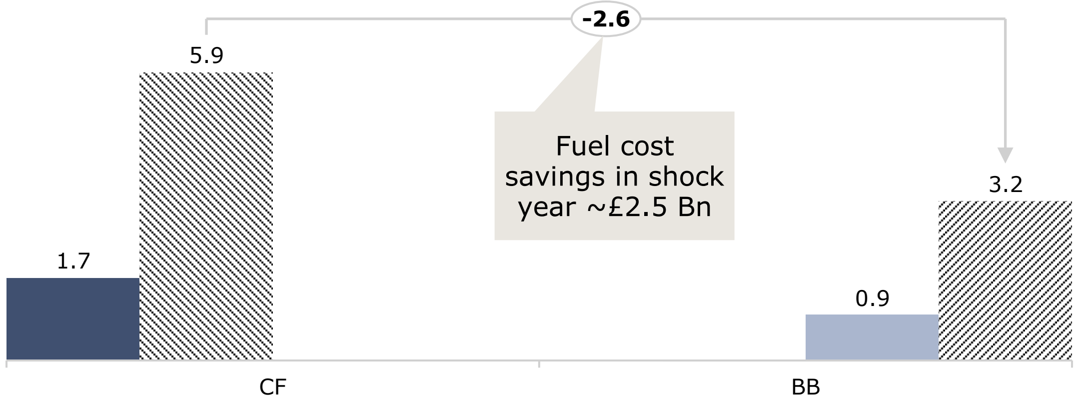
PART 1 | NON-COMMERCIAL BENEFITS – RESILIENCE - GAS PRICE SHOCK

# In the selected year of 2055, the backbone is less impacted by a gas price shock, showing a saving of £2.6 bn

### TOTAL VOLUME OF GAS USED IN SHOCK YEAR 2055, (TWH)




### FUEL COST IN 2055, WITH AND WITHOUT SHOCK GAS PRICE (BN £, REAL 2023)




**Gas Price Shock:**

- Based on ONS SAP data, peak annual gas price (2022) was 3.5× higher than the 2024 average.
- To reflect the 2022 gas price shock, an annual average fuel cost of £80/MWh was applied in the analysis. In contrast, our Base case modelling projects a significantly lower gas price of approximately £23/MWh by 2055.
- All other assumptions held constant to isolate the fuel price impact.

**Key findings:**

- The backbone slightly reduces system variable OPEX by lowering reliance on SMR with CCS and allowing greater use of CCGT running on hydrogen. As a result, the system is marginally less sensitive to gas price shocks compared to the counterfactual.
- Variable OPEX can be disaggregated into two key components: fuel and variable other works costs (VOWC), and Carbon costs
- The impact of the gas price shock on the fuel portion of the variable OPEX has been assessed



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PART 1 | NON-COMMERCIAL BENEFITS - GROSS VALUE ADDED (GVA)

# In absolute terms most investment impacts England, however on a per capita basis Scotland & Wales experience greater investment impacts

## TOTAL UNDISCOUNTED CAPEX SPEND (£BN REAL 2023) BACKBONE SCENARIO

**Scotland**

- 2040 - £**3.9** bn
- 2050 - £**0.8** bn
- 2060 - £**0.1** bn

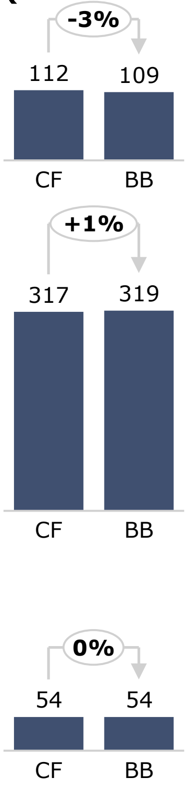
**England**

- 2040 - £**10.4** bn
- 2050 - £**4.2** bn
- 2060 - £**0.2** bn

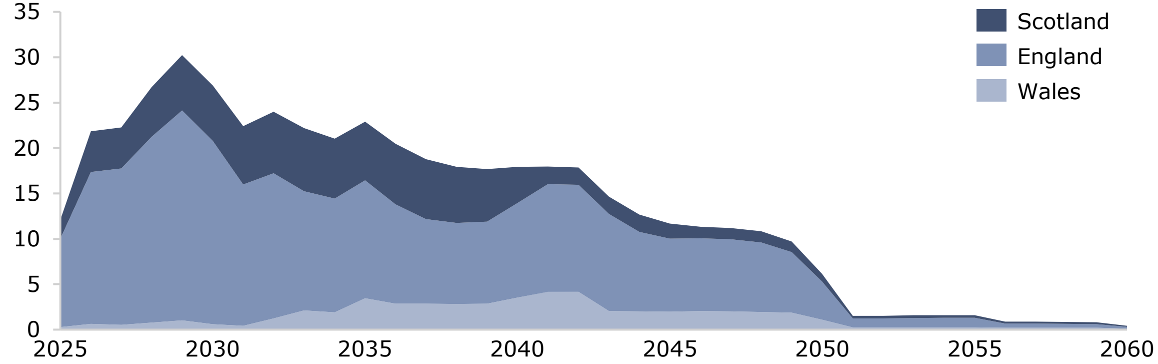
**Wales**

- 2040 - £**3.5** bn
- 2050 - £**1.1** bn
- 2060 - £**0.1** bn

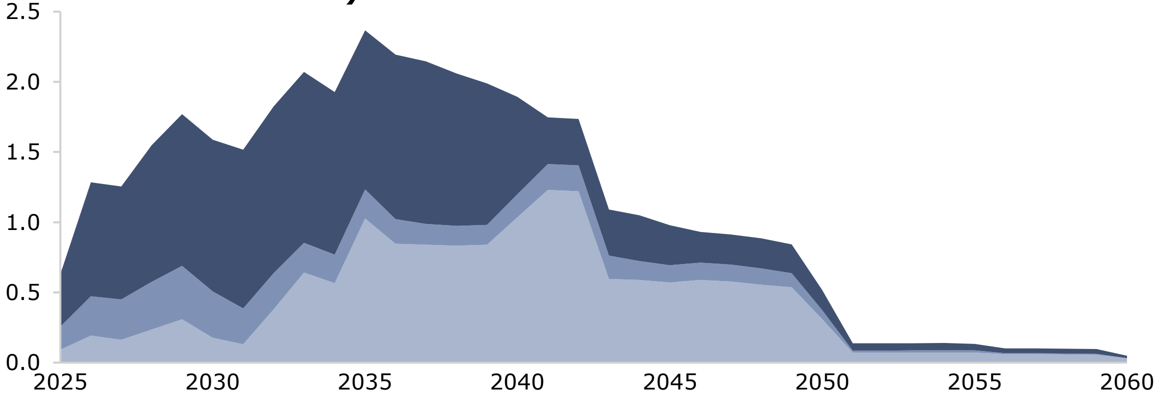
**SUM (2025-2060)**




## ABSOLUTE UNDISCOUNTED CAPEX SPEND £BN REAL 2023 BACKBONE SCENARIO




## UNDISCOUNTED CAPEX SPEND £BN 2023 PER CAPITA (PER MILLION PEOPLE) BACKBONE SCENARIO




Population data for per capita calculations: Office for National Statistics (2025). *National Population Projections: 2022-based*



AFRY

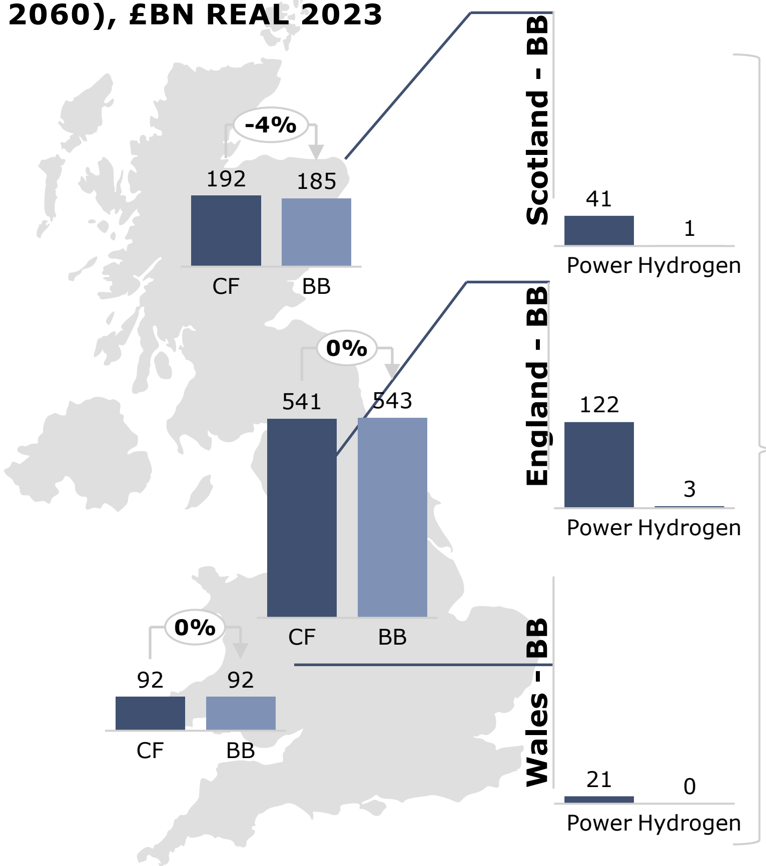
RESTRICTED

PART 1 | NON-COMMERCIAL BENEFITS - GROSS VALUE ADDED (GVA)

# As the backbone requires less investment overall over the modelled period, it has a less positive impact on GVA

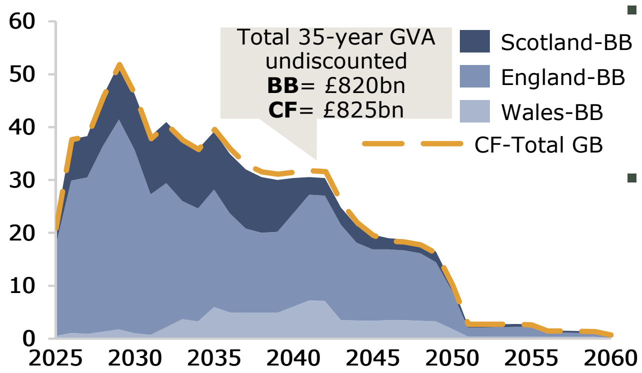
**TOTAL GB GVA AS A RESULT OF DIRECT INVESTMENT (2025-2060), £BN REAL 2023**

**LOCAL CAPEX INVESTMENT 2025-2060, £BN**



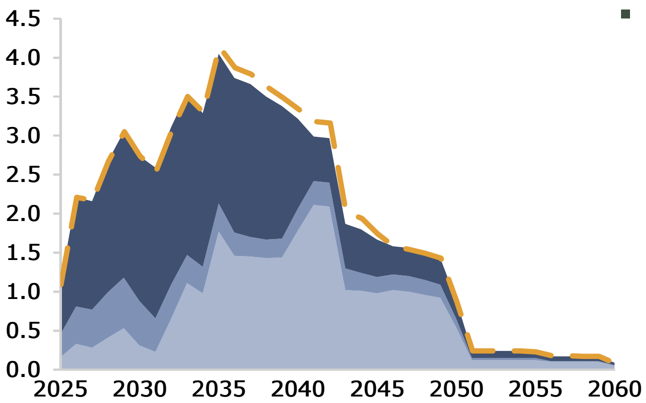

Since multipliers represent **UK-specific linkages, local (UK) CAPEX spend** was calculated first—removing imports for both power and hydrogen sectors — so that the multiplier is applied only to expenditure that actually stimulates value added within the UK economy. This was done using ONS data.

**GVA, £BN REAL 2023 - BACKBONE SCENARIO**




- GVA measures the net economic contribution — the value of goods and services produced within the UK economy as a result of the project's investment.
- By using Type I GVA multipliers, the results show the production-side impact only — the value added generated through the project and its suppliers, but not the wider ripple from household consumption.

**GVA PER CAPITA , £BN REAL 2023 - BACKBONE SCENARIO**



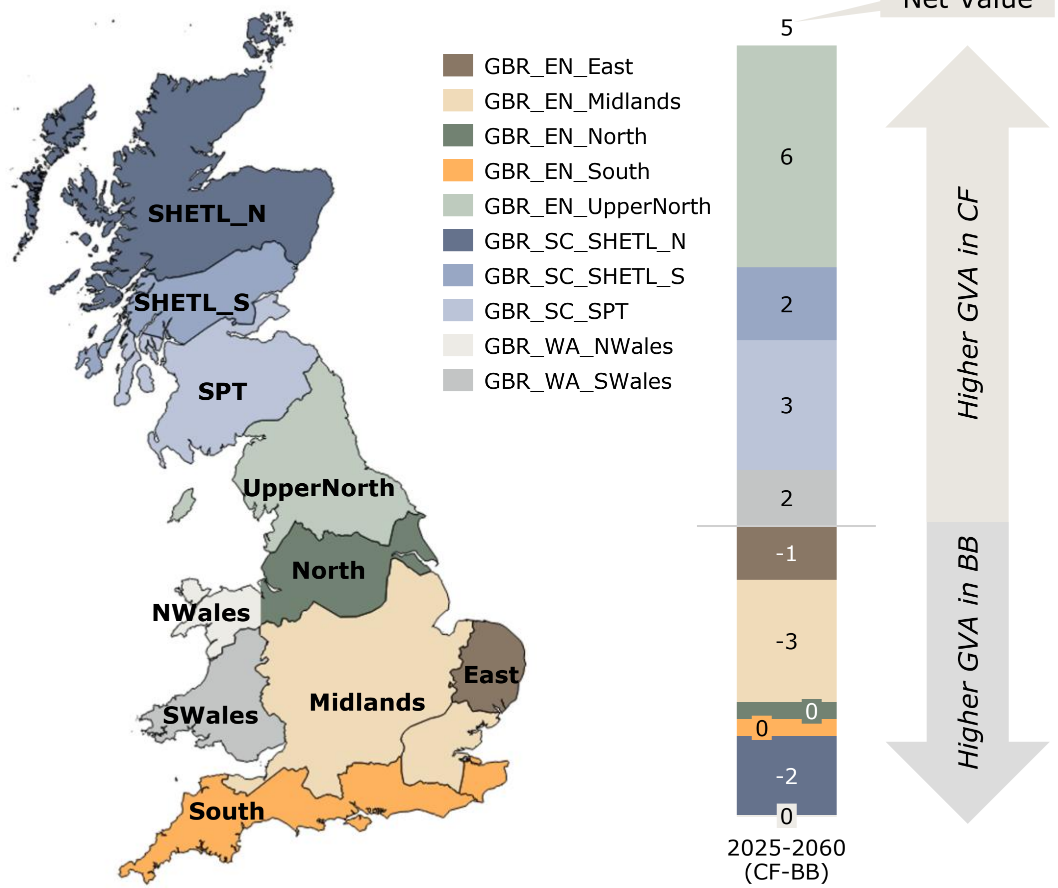

- Similar to CAPEX, on a per CAPITA basis the GVA looks to benefit Scotland and Wales more than England

Office for National Statistics (ONS), *Input–Output Analytical Tables, United Kingdom: 2022 edition (consistent with Blue Book 2023)*, Industry-by-Industry multipliers. Multipliers: Power: D351-Electric power generation, transmission and distribution–GVA Multiplier 4.337. Hydrogen: D352_3 Manufacture of gas; distribution of gaseous fuels through mains; steam and aircon supply–Multiplier 5.665

PART 1 | NON-COMMERCIAL BENEFITS - GROSS VALUE ADDED (GVA)

# The Backbone scenario alters the regional distribution of investment, increasing GVA in a few areas; this shift comes at the expense of others

**GVA DELTA SUM (2025-2060), CF-BB, £Bn real 2023**




## COMMENTS

- To achieve greater spatial granularity, each zone's share of total GB CAPEX-weighted investment was calculated annually and applied to the corresponding GB-wide GVA, producing proportional regional GVA estimates that reflect both build magnitude and technology mix.
- The delta between the Counterfactual and the Backbone shows the shift between regions in investment.
- Power zones have been used as it is possible to aggregate hydrogen capacity into a power zone but to disaggregate power capacity into hydrogen zones would be problematic.

**Key take aways:**

- The key takeaways are a lower total GVA and a shift in its regional distribution.
- While the reduction in overall GVA may seem counterintuitive, it aligns with the underlying analysis, which shows that the most significant differences between the scenarios lie in CAPEX in the early to middle years.
- The regional re-distribution of GVA follows the type and magnitude of power/hydrogen investment in each zone.
- It has been noted that this assumes that local supply chain capabilities reflect national averages and this may distort the outcomes here.



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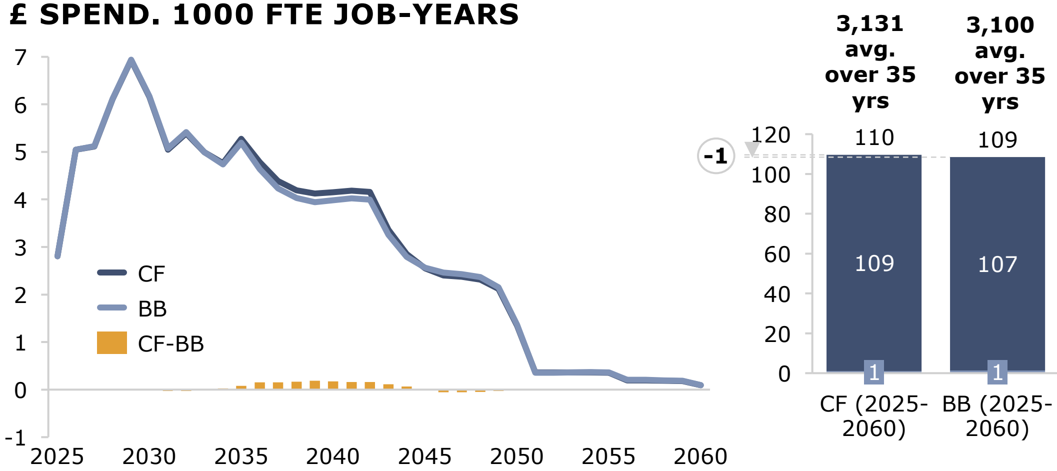
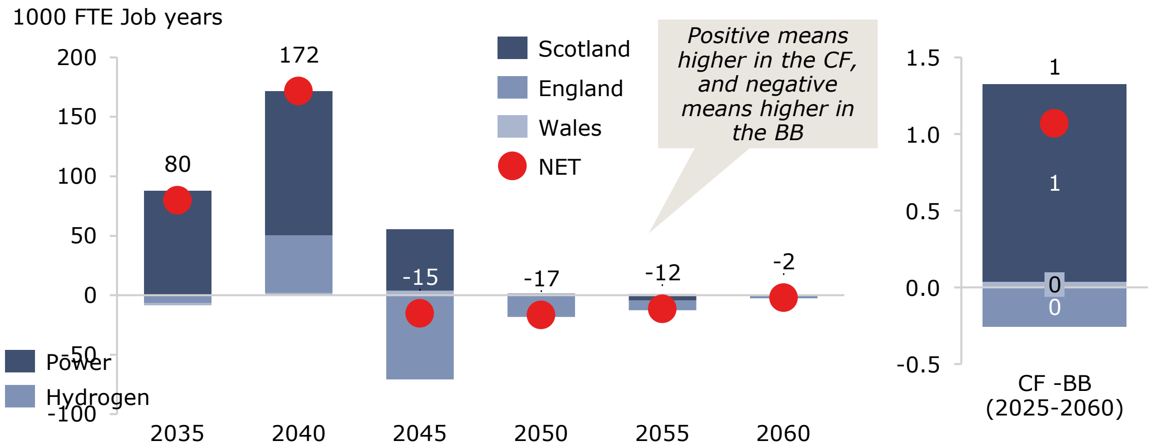
# Overall national job creation is broadly similar across both pathways; the Backbone scenario does not deliver a significant employment uplift

## ESTIMATES OF THE IMPACT ON FTE EMPLOYMENT PER MILLION £ SPEND. 1000 FTE JOB-YEARS




## FTE JOB YEAR CREATION, GEOGRAPHICAL SPREAD, CF-BB



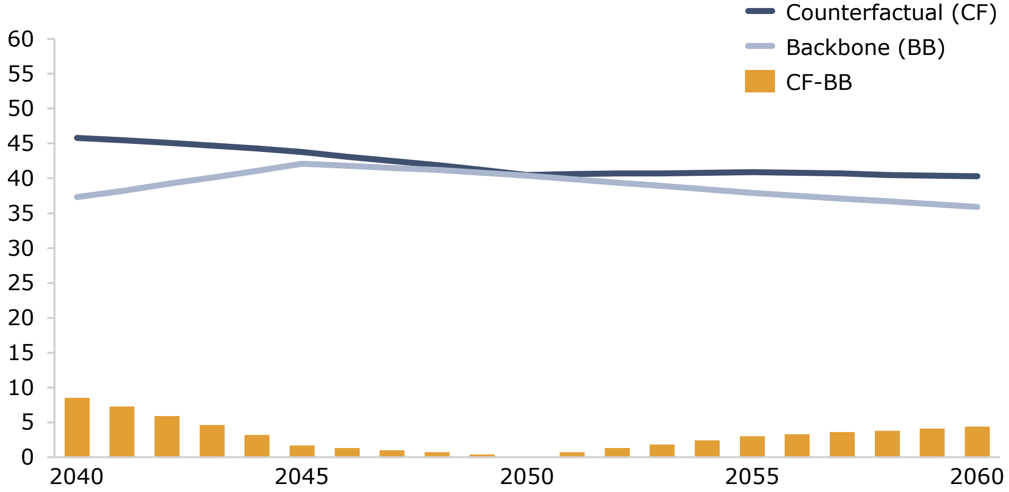

- Applied ONS (2020) employment multipliers to UK-adjusted CAPEX (proportion of CAPEX to be assigned to UK domestic spend) to estimate Full-Time Equivalent (FTE) job-years supported annually.
- Multipliers capture direct and indirect UK employment effects (Type I).
- FTEs represent job-years, i.e. one full-time role sustained for one year.
- Employment in the power sector is more prominent because hydrogen receives only 2% of total domestic investment. Moreover, the ONS Full-Time Equivalent employment multiplier for hydrogen is significantly lower than for power—0.34 FTE per £1 million spent on hydrogen compared to 0.58 FTE per £1 million spent on power.
- The Backbone scenario generates approximately 1,000 fewer FTE job years compared to the counterfactual, resulting in a net employment delta of 1,000 FTE job years. This reflects the lower investment requirements of the Backbone scenario.

Source: ONS Employment multipliers and effects in the UK, 2022
Proxy industry multipliers been used for hydrogen. Also, if CAPEX in $H_2$ were more locally retained—through targeted promotion of local supply chains—the regional Employment outcomes could differ

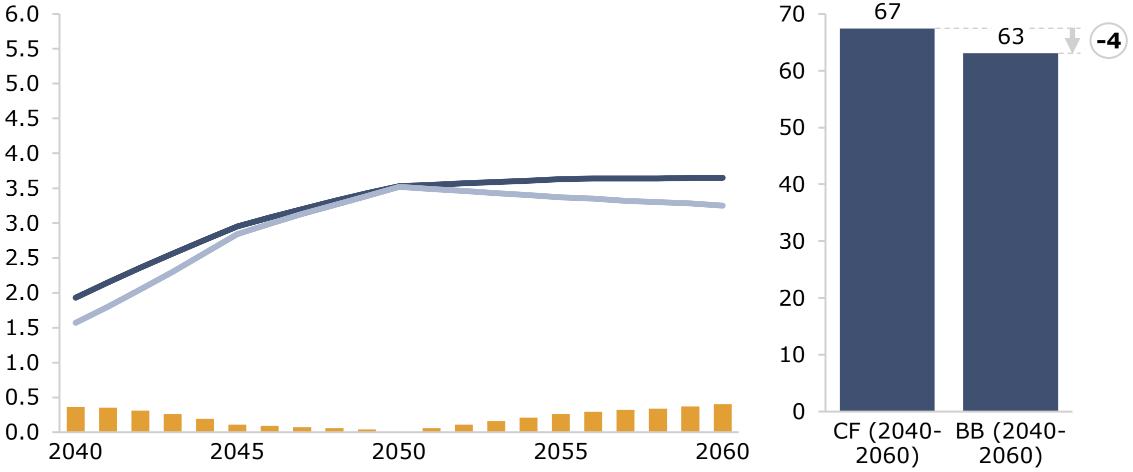
PART 1 | NON-COMMERCIAL BENEFITS - INDUSTRIAL COMPETITIVENESS

# The backbone lowers national hydrogen prices, reducing annual industrial hydrogen costs and slightly improving industrial competitiveness

## NATIONAL HYDROGEN PRICE* (£/MWH HHV, REAL 2023)




## ANNUAL INDUSTRIAL HYDROGEN COST (BN £, REAL 2023)




- The chart on the left displays the demand-weighted average national hydrogen price, while the chart on the right illustrates the annual cost of hydrogen use in the industrial sector based on the corresponding hydrogen price.
- The backbone contributes to a decrease in the national hydrogen price, as shown by the difference between the two cases. This leads to reduced annual costs for fulfilling hydrogen demand in the industrial sector. This improves industrial competitiveness by having access to a lower cost hydrogen supply.
- Between 2040**-2060 industrial hydrogen consumers will save approximately £4 Bn, with an annual average saving of £200 Mn over 20 years

*National hydrogen price is based on non-power demand weighted average
**2040 is assumed as the point from which a commoditised hydrogen market emerges

# Contents



# The analysis carried out in Part 1 of this study shows that the commercial case for a hydrogen backbone under the Base assumptions is marginal

**Development of a well reasoned Base case**

The Base case scenario modelling demonstrates that inclusion of a backbone in GB increases deployment of electrolysers and salt cavern storage, while reducing the need for SMR, electricity transmission and LDES compared to under a Counterfactual case. As such, the backbone has potential to impact both the installed capacity mix of power plants, storage and electricity transmission, and the hourly dispatch and operation of the GB electricity and hydrogen systems

**Commercial assessment of the needs case**

A hydrogen backbone does not dramatically improve the economics of the GB electricity and hydrogen systems based on the Base case modelling and the metrics used in Part 1. In this analysis, the NPV and total system cost savings (covering CAPEX, fixed OPEX and variable OPEX) under the Base case scenario assumptions show little improvement with the inclusion of a backbone compared to under a Counterfactual case without a backbone.

**Assessment of non-commercial benefits**

The assessment of non-commercial benefits shows that the Backbone provides wider system value beyond the marginal commercial case, including societal $CO_2$ cost savings, reduced curtailment, higher green hydrogen production and lower gas reliance. However, these benefits are not sufficient to materially change the overall Base case conclusion, as impacts on GVA and employment are limited and some regional impacts, such as water stress, require further analysis.

**Key Findings**

The analysis indicates that, under the well-reasoned Base Case assumptions, the economic case for a hydrogen backbone is limited.

# Contents



# Initially four sensitivities were modelled to identify potential tipping points and highlight impacts of uncertainties

## SENSITIVITIES

1

The capacity of the retained pipelines stays the same as the Base case


**1. Reduced and delayed hydrogen backbone**

- No commissioning of hydrogen pipelines before **2040**, and the national reach of the backbone infrastructure is reduced to Humberside and Merseyside from Scotland.
- Reduced backbone length from **~1700 km to ~900 km**

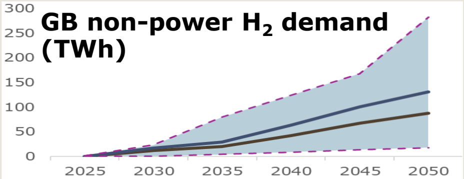
2

| Electrolyser costs | | |
|---|---|---|
| **Avg. 2025-2060** | **Base case** | **Sensitivity** |
| **Capex £/kw** | 248 | 1520 |
| **Opex £/kw/yr** | 42 | 55 |

**2. Reduced blue $H_2$ production capture rates & higher electrolyser costs**

- Reduced carbon capture rates for blue hydrogen production **95% to 85%**
- Increased electrolyser costs to match NESO's 'Levelised Cost of Green Hydrogen' dataset (October 2023)

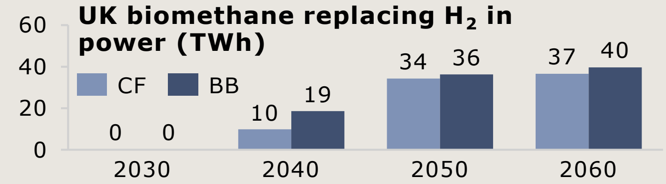
3




**3. Higher non-power hydrogen demand**

- Non-power hydrogen demand rises by **50%** nationally, with broader distribution across zones.
- By 2060 demand rises from **90TWh** (Base case) to **136TWh** (Sensitivity 3)

4




**4. Biomethane vs Hydrogen**

- Biomethane replaces all hydrogen as a fuel in the power sector for both Counterfactual (no backbone) and the Backbone case.
- Biomethane as fuel used in power reaches **~40TWh** by 2060 in the Backbone case

Tipping points: Changes in drivers/assumptions that result in the needs case for a national hydrogen backbone materially changing. can impact the commercial needs case positively or negatively.

**Modelled in Bid3**
**Backbone iterated**



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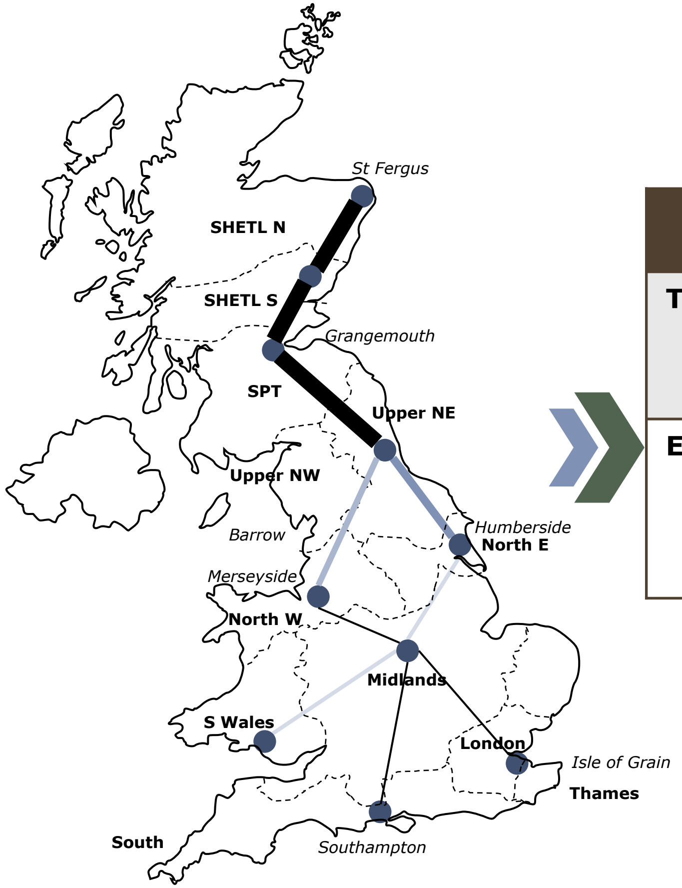
# Contents



# The sensitivity of the needs case to an alternative more cautious deployment of the backbone – both in terms of timing and extent – was tested

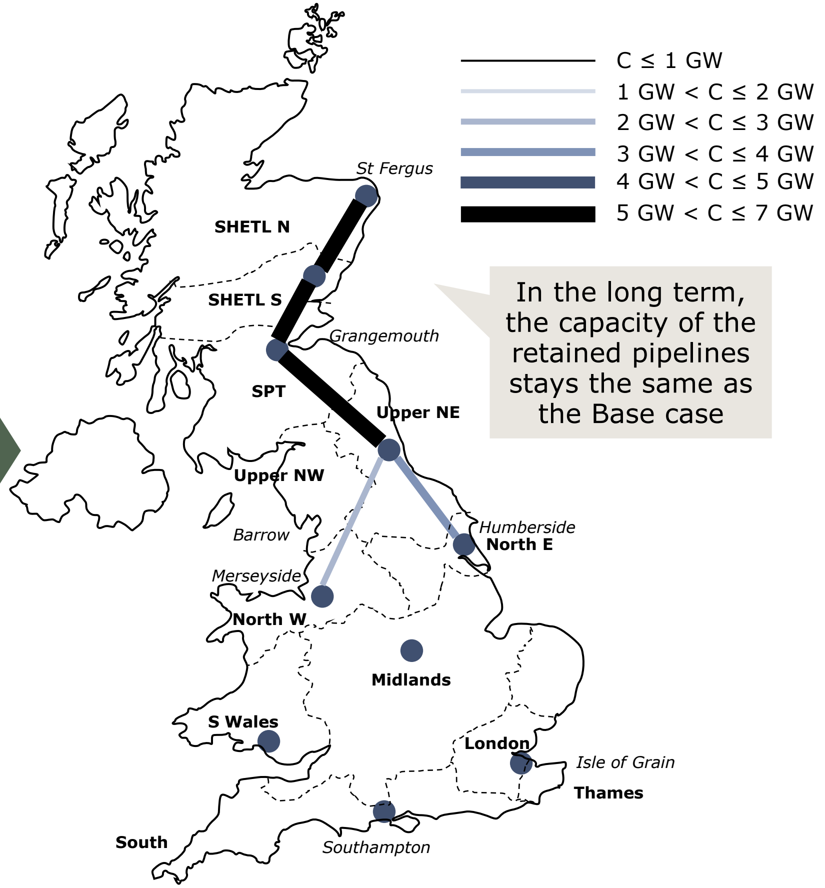
## BASE CASE BACKBONE CONFIGURATION IN 2050




| | Base case | Sensitivity |
|---|---|---|
| **Timing** | $H_2$ pipeline commissioning as early as 2030 | No $H_2$ pipeline commissioning before 2040 |
| **Extent** | Whole GB | No $H_2$ backbone south of North W and North E zones |

Pipelines located south of North W and North E zones were excluded from the sensitivity analysis because of lower hydrogen demand combined with considerably lower pipeline capacity in the final configuration of the Base case

## SENSITIVITY 1 CONFIGURATION IN 2050




In the long term, the capacity of the retained pipelines stays the same as the Base case

# The reduced backbone removes southern branches but retains long-term capacity in northern GB zones

## BASE CASE CONFIGURATION CAPACITIES (GW)

| Zone from | Zone to | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|
| SHETL N | SHETL S | - | 1.80 | 5.30 | 5.30 | 6.50 |
| SHETL S | SPT | - | 2.10 | 5.50 | 5.50 | 6.80 |
| Upper NE | SPT | - | 2.30 | 5.80 | 5.80 | 7.00 |
| NE | UNE | 1.00 | 3.80 | 3.80 | 3.80 | 3.80 |
| Upper NE | NW | - | 1.40 | 2.20 | 2.20 | 2.20 |
| Midlands | NW | - | 1.00 | 1.00 | 1.00 | 1.00 |
| Midlands | NE | - | 2.00 | 2.00 | 2.00 | 2.00 |
| Midlands | S Wales | - | - | 1.40 | 1.40 | 1.40 |
| Midlands | South | - | - | - | - | 0.75 |
| London | Midlands | - | - | - | 0.50 | 0.50 |

Key: Change in capacity compared to Base case configuration

Increase | Unchanged | Decrease

## SENSITIVITY 1 CONFIGURATION CAPACITIES (GW)

| Zone from | Zone to | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|
| SHETL N | SHETL S | - | - | 5.30 | 5.30 | 6.50 |
| SHETL S | SPT | - | - | 5.50 | 5.50 | 6.80 |
| Upper NE | SPT | - | - | 5.80 | 5.80 | 7.00 |
| NE | UNE | - | - | 3.80 | 3.80 | 3.80 |
| Upper NE | NW | - | - | 2.20 | 2.20 | 2.20 |
| Midlands | NW | - | - | - | - | - |
| Midlands | NE | - | - | - | - | - |
| Midlands | S Wales | - | - | - | - | - |
| Midlands | South | - | - | - | - | - |
| London | Midlands | - | - | - | - | - |

| 2050 backbone values | Base case | Sensitivity | % change |
|---|---|---|---|
| **Total Capacity*** | 32 GW | 26 GW | -18% |
| **Total Length*** | 1700 km | 884 km | -48% |

* Reflects the sum of all pipelines in the backbone in 2050.

# Removal of the backbone in southern zones results in increased SMR-CCS build-out, with a slight increase in transmission reinforcement and storage

| KEY STORYLINES | |
|---|---|
| 1 | **Hydrogen production:** the lack of a backbone in the southern region gives SMR-CCS an advantage over electrolysers. As a result, a portion of the electrolyser capacity in southern areas, mainly in London and the South Wales (which currently lack a backbone), is substituted with SMR-CCS to satisfy local demand versus the Base case. |
| 2 | **Hydrogen storage:** the reduction in the extent of the backbone slightly lowers the demand for hydrogen storage in the Northern zones, leading to a decrease in salt cavern storage here. Conversely, the lack of a backbone in the southern regions raises the need for hydrogen storage in the south. However, this increase is modest since the south has less potential for salt caverns, and hydrogen storage tanks are significantly more costly. Additionally, the greater capacity of SMR-CCS, which provides continuous hydrogen production, also impacts this demand for storage. |
| 3 | **Dispatchable generation:** overall, there is very little change in the total dispatchable capacity built compared to the Base case. CCGT $H_2$ capacity in the South zone increased slightly to replace the onshore wind. |
| 4 | **Renewables:** onshore wind capacity in the Midlands has slightly decreased, corresponding with a reduction in electrolyser capacity intended to produce and transport hydrogen to adjacent zones through the backbone. |
| 5 | **Electricity storage:** there are slight changes in electricity storage capacity with a marginal increase in LDES to facilitate more flow/generation of RES to the southern regions |
| 6 | **Electricity transmission network:** there is a minor adjustment in the transmission network, with somewhat increased reinforcement to the Midlands from adjacent regions to accommodate electricity demand, resulting from a reduced expansion of onshore wind capacity |



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# The reduced backbone in Sensitivity 1 results in minimal change to the total system costs between the Counterfactual and Backbone cases

## KEY MESSAGES

**1** Very slight changes to the system cost occur under Sensitivity 1 ("BB Sen1") compared to the Backbone Base case with the difference being less than 1% (NPV – BB being lower). Despite the marginal change to the system costs, the BB Sen1 case remains lower than the Counterfactual case.

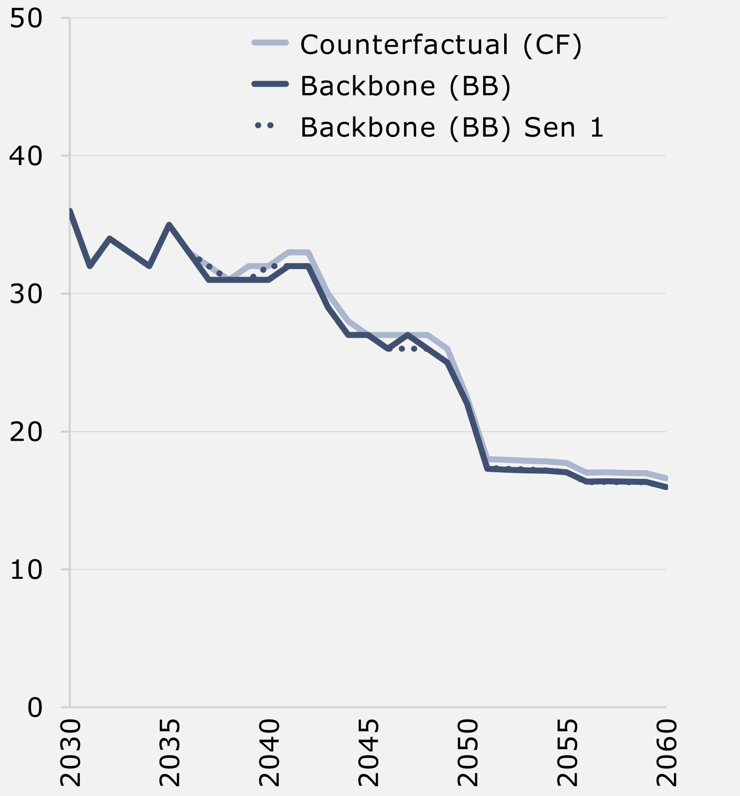
**2** In BB Sen1 removing pipeline capacity specifically in the southern regions leads to the build of SMR-CCS in general, which increases the variable OPEX of the system compared to the Backbone Base case.

There are also slight increases in transmission and LDES costs due to marginally higher build-out in their capacity.

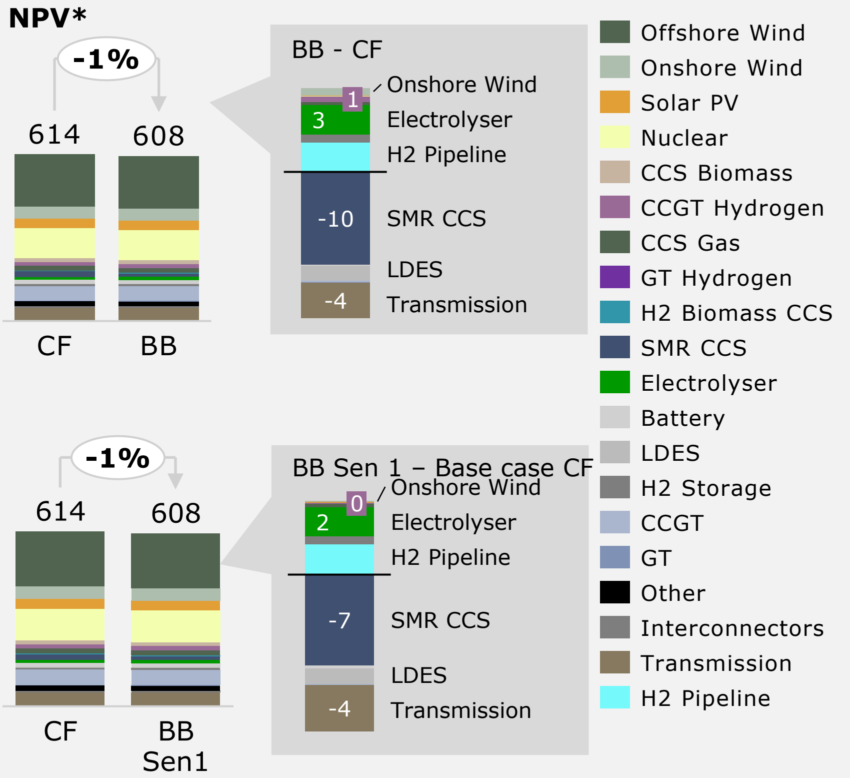
**3** Due to the reduction in pipeline capacity, costs for the pipeline decrease, resulting in lower electrolyser and onshore wind build-out. This counters the additional costs for SMR-CCS, transmission and LDES, leading to a broadly similar final NPV.

## SENSITIVITY 1 SYSTEM COST COMPARISON

ANNUAL SYSTEM COST (BN £, REAL 2023)



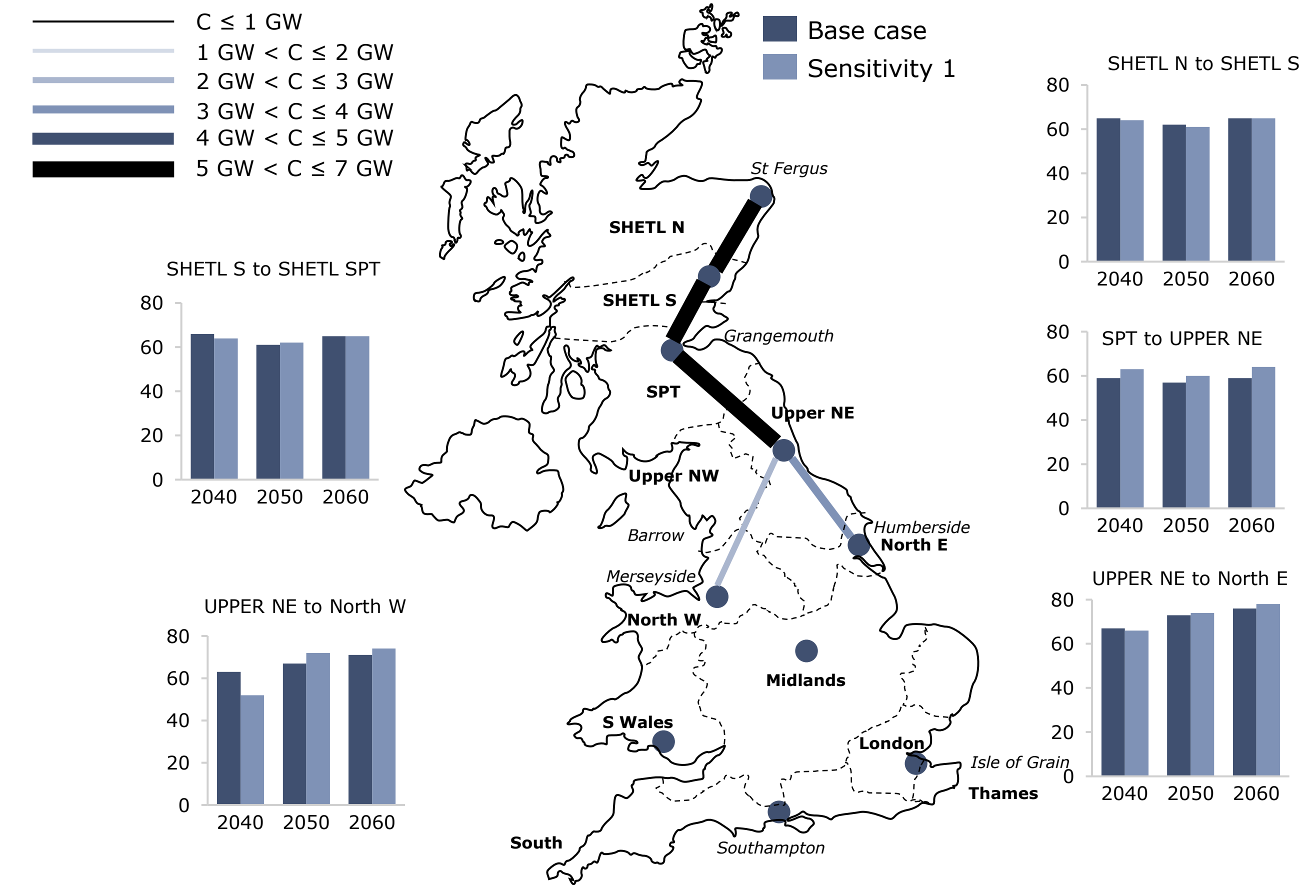

TOTAL SYSTEM COST BY TECHNOLOGY (BN £, REAL 2023)




Notes: CF – Counterfactual scenario, BB – Backbone scenario. Where there is no "Sen" mentioned with CF or BB then this refers to the Base case.
* NPV is on a 35-year (2025-2060) period using a rate of 3.5% for the first 30 years and 3% for the last 5 years

# Over the years when the backbone is present in the sensitivity, pipeline utilisation remains mostly consistent with the Base case

## HYDROGEN PIPES UTILISATION (%)




Note: Pipeline capacity in map is shown for the year 2050.

## COMMENTARY

- Starting in 2040, as the backbone emerges in Sensitivity 1, the pipeline utilisation stays comparable to the Base case within the applicable regions
- In regions where the backbone remains unaffected in the sensitivity over the long term, hydrogen production also stays mostly steady. For instance, SMR-CCS capacity does not change, while the expansion of electrolysers sees only a slight increase. This contributes to the pipeline utilisation in these regions remaining fairly similar to the Base case.
- Certain pipelines experience a modest increase in utilisation in the sensitivity, mainly driven by the increased electrolyser build-out required to compensate for the lack of hydrogen imports from Wales & the southern zones.

# The sensitivity supports the case for a simpler, low-regrets design, but if not managed carefully, risks and barriers could undermine long-term benefits

**Sensitivity insights**

- Marginal cost savings exist under Sensitivity 1 vis-à-vis the Base case CF and are practically identical to the Base case BB scenario.
- Modelling shows the reduced backbone delivers equivalent cost savings and decarbonisation outcomes as the larger backbone
- A 10-year delay (from 2030 to 2040) does not materially increase total system costs in aggregate (35 years); supporting the case for a simpler, low-regrets backbone design aligned with more realistic delivery timelines.

**Limits of the sensitivity**

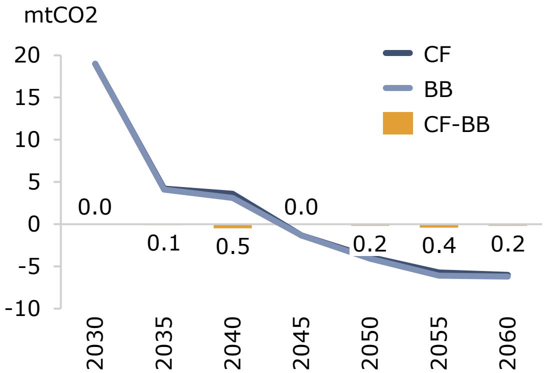
- The sensitivity draws some light on the potential impacts of the "**Public Acceptability**" barrier
- Risks around opposition and permitting challenges often trigger a cascade of secondary effects which would challenge modelling assumptions in the following areas:
  - Increased development CAPEX from delays and mitigation (e.g., re-routing).
  - Delayed start *(part of this sensitivity)* and increase in build times.
  - Risk of stranded assets or abandoned projects if parts of the backbone become disconnected or unviable (e.g. salt cavern storage).

**Wider risks beyond the sensitivity**

- Opportunity costs for decarbonisation and wider benefits if delays hinder coordinated infrastructure.
- As the country continues to pursue its environmental and decarbonisation targets, other investments will inevitably proceed in parallel. This can lead to a fragmented investment landscape, where infrastructure is developed along divergent paths.
- Under such a scenario, the backbone's intended benefits may be significantly eroded. By the time the full transmission project is completed, the Base case will have evolved—investments made in the interim may not align with the backbone's design, leading to inefficiencies and missed opportunities for system integration.

# Non-commercial benefits have reduced in line with reduced electrolyser and $H_2$ storage buildout – a consequence of the reduced backbone

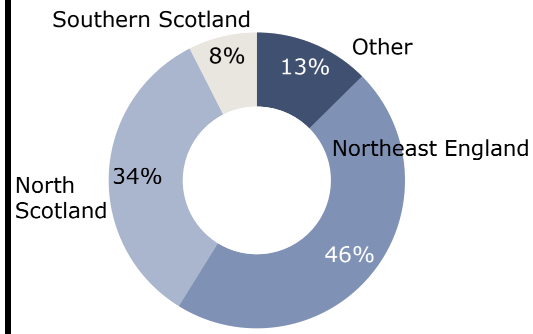
## CO₂ EMISSION VARIATIONS & SOCIETAL COST OF CARBON




- **5.4 mtCO2** emission savings (vs 6.6 Base case) over 35 years due to the reduced backbone
- **£696m NPV** (Real 2023) of societal cost of carbon savings due to the reduced backbone vs Counterfactual (vs £920m Base case)
- Electrolysers replaced by SMR-CCS in southern regions due to absence of the backbone. This drives increased emissions vs the Base case BB scenario.

## WATER STRESS

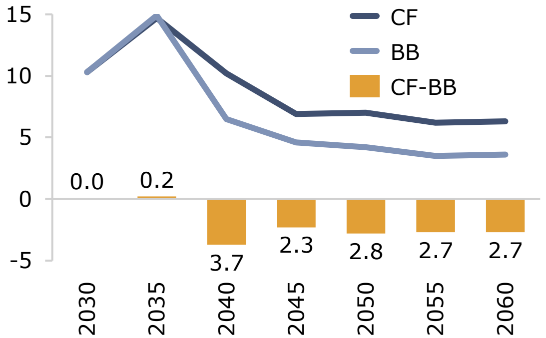
**Regional concentration of water consumption for electrolytic $H_2$ production by 2050**




- By 2050, water use pressures are concentrated mainly in the Northeast of England, Northern Scotland, and Southern Scotland.
- Water pressures may intensify under this sensitivity due to the concentration of electrolytic $H_2$ production in Northern Scotland which has existing water scarcity issues along its east coast
- South Wales was previously identified as an area of concern, but it no longer is in this sensitivity.

## RES CURTAILMENT[1]

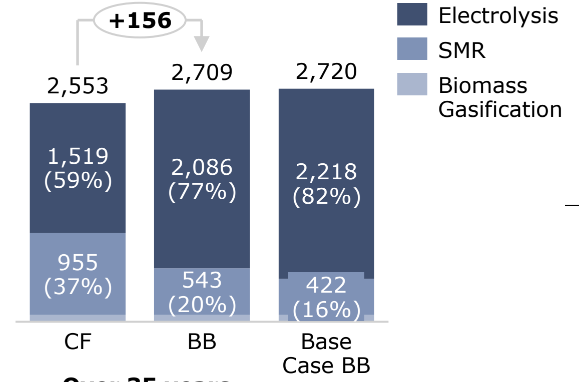
% Curtailment of Total RES (Wind Solar)




- Across wind and solar the reduced backbone case has a total of **~442 TWh** of curtailment savings (vs Base case 520TWh) compared to the Counterfactual over the 35-years
- With reduced flexible demand (electrolysis) or storage, the system becomes less capable of integrating variable renewables. Therefore, less electrolysis and less H₂ storage leads to higher curtailment of wind and solar.

## HYDROGEN PRODUCTION

**TWh**




**Over 35 years**

- Over the 35 years the reduced backbone in Sensitivity 1 enables an *additional* **156 TWh** (vs 167[2] TWh Base case BB-CF) of domestic production of hydrogen of which **77%** (vs 82% Base case) is electrolytic green hydrogen.
- Hydrogen production within this sensitivity's BB scenario and the Base case BB scenario are almost identical over the 35-year period, the difference is the shift to blue hydrogen production given the reduced nature of the backbone.

1. %Curtailment = Curtailment TWh / (Generation TWh + Curtailment TWh), 2. see slide 46



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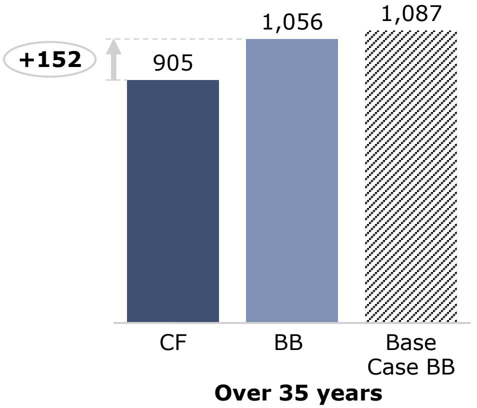
# The reduced backbone slightly increases reliance on gas vs the Base case while energy diversity and imports of power remain largely unchanged

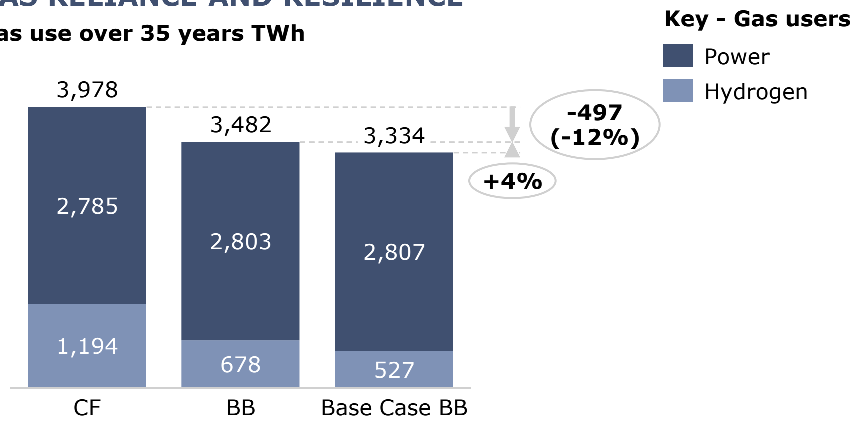
## POWER IMPORTS




- **152 TWh** more power imports between the BB and CF within this sensitivity.
- Power imports follow the same logic as in the Base case where they have increased as a result of introducing the backbone.
- With the Backbone, electrolysers provide flexibility while absorbing cheap power, reducing power export opportunities as electricity that would have been exported in the CF is instead used domestically for $H_2$ production. Conversely, when renewable output is low, GB may import power more to sustain electrolyser demand.

## GAS RELIANCE AND RESILIENCE

**Gas use over 35 years TWh**




- **~497 TWh** of gas use savings due to the Backbone versus the CF.
- The reduced backbone enables less electrolysers and relies more on SMR-CCS to produce hydrogen from natural gas. Consequently, natural gas demand is higher vs the Base case BB scenario.
- The backbone slightly reduces system variable OPEX by lowering reliance on SMR-CCS, and allowing greater use of CCGT running on hydrogen. As a result, the system is marginally less sensitive to gas price shocks compared to the Counterfactual.
- Given gas reliance is comparable to the Base case backbone scenario, the impact on total costs reductions due to a spike in gas prices will also be comparable.

# Contents



PART 2 | SENSITIVITY 2 - CCS CAPTURE RATE FOR BLUE $H_2$ PRODUCTION & HIGHER ELECTROLYSER COSTS

# In this sensitivity, capture rates for blue hydrogen production were reduced and electrolyser costs were increased

## CCS CAPTURE RATE FOR BLUE $H_2$ (SMR-CCS) PRODUCTION

***NOTE**: The Environment Agency has provided guidance indicating that $CO_2$ capture rates should be a minimum of 95%. However, in this sensitivity, a reduced capture rate of 85% has been assumed purely for analytical purposes — to test the impact of lower performance on the system. This scenario does not aim to reflect any regulatory penalties or compliance implications associated with reduced capture rates.*

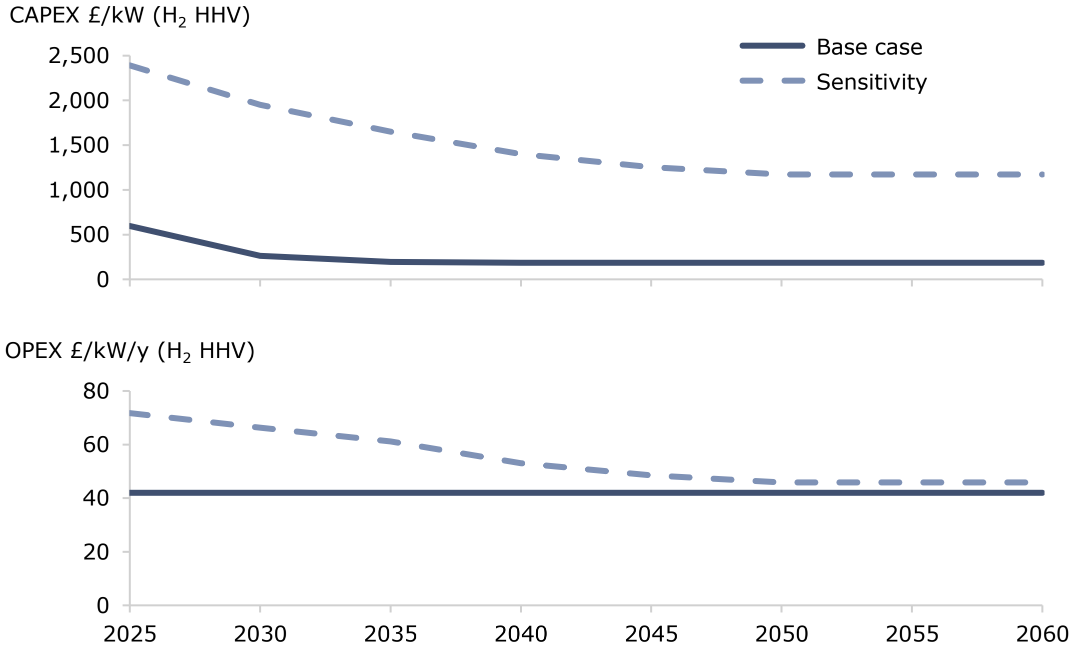
| | Base case | Sensitivity |
|---|---|---|
| **Blue hydrogen production carbon capture rate** | 95% across all future years | 85% across all future years |

In this sensitivity, the carbon capture rate for blue hydrogen production was lowered from 95% to 85%. This more conservative estimate accounts for greater operational variability and possible downtime, acknowledging that actual capture rates may fall short of vendor targets in suboptimal conditions.

The carbon capture rates for other CCS types, including Biomass CCS and Gas CCS used in power generation, stayed the same as those in the Base case.

## ELECTROLYSER COSTS*

Base case technology cost projections follow the assumptions adopted in the CCC's 7th Carbon Budget. However, these assumptions are considerably lower than the electrolyser cost estimates presented in the NESO 'Levelised Cost of Green Hydrogen' dataset (October 2023)




*Source of electrolyser costs for sensitivity: https://www.neso.energy/data-portal/levelised-cost-green-hydrogen

# In Sensitivity 2, higher electrolyser costs make SMR-CCS preferable for hydrogen production, even with lower $CO_2$ capture rates

| KEY STORYLINES | |
|---|---|
| 1 | **Hydrogen production:**<br>**Changes in sensitivity compared to Base case**: electrolyser capacity declines significantly, while SMR-CCS capacity increases substantially compared to both the Counterfactual and Backbone base cases. In the North and Upper North where there are key demand centres, electrolysers are almost entirely replaced by SMR-CCS due to higher electrolyser costs.<br>**Changes in BB compared to CF in sensitivity:** Similar to the Base case, with the introduction of the backbone, more electrolysers are built, primarily in Scotland, due to access to low-cost electricity and the ability to transport hydrogen to the North of England, which is the main demand centre. |
| 2 | **Hydrogen storage:**<br>**Changes in sensitivity compared to Base case:** significant reduction in both tank and salt cavern storage due to lower intermittent electrolytic hydrogen production deployment in both BB and CF in Sensitivity 2 compared to their respective Base cases.<br>**Changes in BB compared to CF in sensitivity:** incorporating the backbone leads to a rise in the build of salt caverns in the North, driven by the lower cost of hydrogen supplied from Scotland, while the development of hydrogen storage tanks declines further. |
| 3 | **Dispatchable generation:** in this sensitivity, the rise in electrolyser costs, coupled with increased production from SMR-CCS, lead to higher average hydrogen production costs, reducing the competitiveness of CCGT hydrogen. Consequently, CCGT $H_2$ capacity decreases compared to the Base case BB scenario. The generation gap is largely substituted by existing unabated CCGT generation in the medium term. |
| 4 | **Electricity transmission network:** overall, in the sensitivity there is a minor change in the electricity transmission network compared to the Base case. In the sensitivity, the addition of the backbone results in a decrease in network reinforcement compared to the Counterfactual case, but to a lesser extent compared to the Base case. This is due to more localised SMR-CCS capacities in the southern zones. |
| 5 | **Electricity Storage:** in the sensitivity, hydrogen becomes less competitive as a flexibility solution. Consequently, there is a notable increase in LDES capacity relative to the Base case. |
| 6 | **Renewables:** Due to a significantly reduced electrolyser build in the sensitivity case, the expansion of RES, mainly wind capacity, declines relative to the Base case. The majority of this decline takes place in the Midlands where the decrease in electrolyser capacity is most noticeable. |

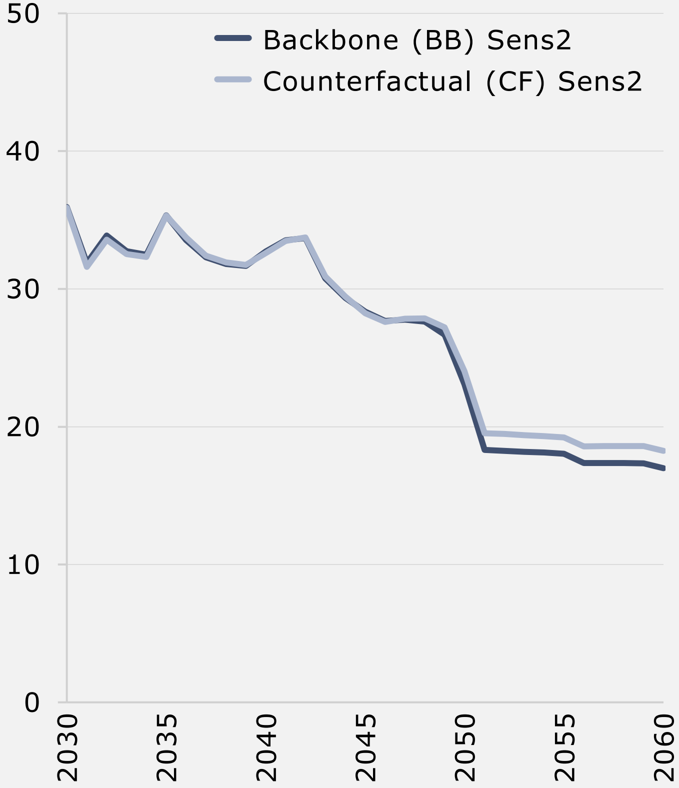
# Higher electrolyser costs and lower SMR-CCS capture rates do not significantly affect the backbone's justification

## KEY MESSAGES

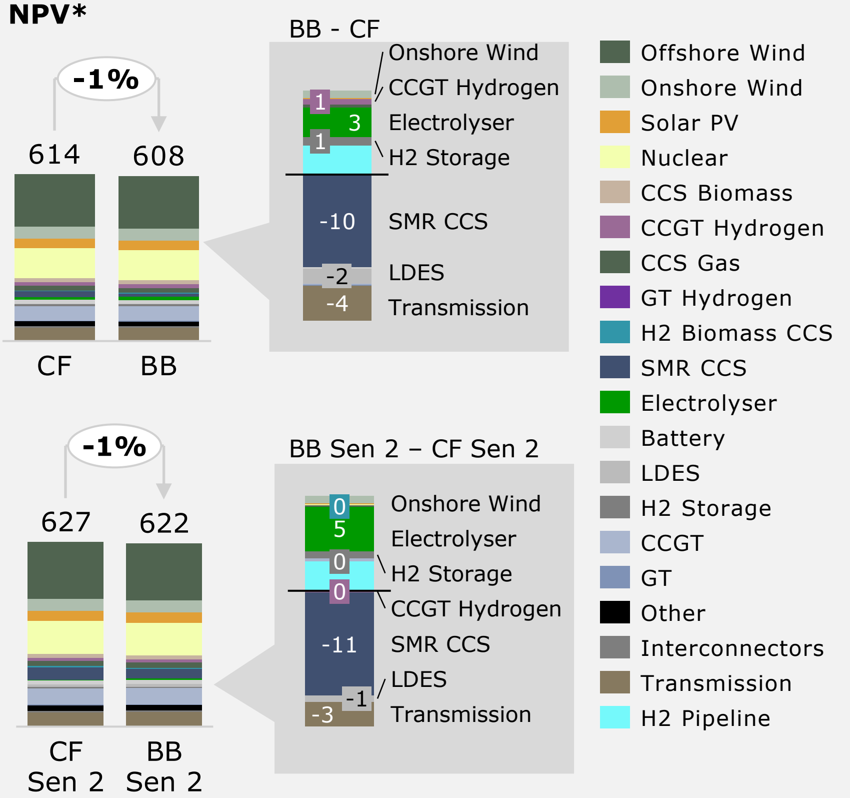
| | |
|---|---|
| **1** | Total system costs under Sensitivity 2 increase in both BB and CF cases compared to the Base case due to higher electrolyser costs and a larger build-out of SMR-CCS. |
| **2** | The cost savings from the backbone in this sensitivity are 17%** *lower* than in the Base case, but this still only represents ~ 1% of the overall system costs. This suggests that higher electrolyser costs and lower capture rates for SMR-CCS does not materially strengthen or weaken the case for the backbone, consistent with what was observed in the Base case. Overall backbone utilisation is lower in this sensitivity compared to the Base case as the system becomes more reliant on SMR-CCS for $H_2$ production. (BB capacities have not been optimised for the sensitivities; additional marginal pipeline cost savings may still be achievable here). |
| **3** | Net savings from the backbone in this sensitivity fell from £~6B to £~5B in NPV terms, indicating a weaker case for the backbone. The slightly lower savings in this sensitivity compared to Base case stems from higher SMR-CCS dependence while the BB enables limited electrolyser build. This leads to a rise in variable OPEX driven by higher fuel costs associated with $H_2$ production. |

## SENSITIVITY 2 SYSTEM COST COMPARISON

ANNUAL SYSTEM COST (BN £, REAL 2023)




TOTAL SYSTEM COST BY TECHNOLOGY (BN £, REAL 2023)

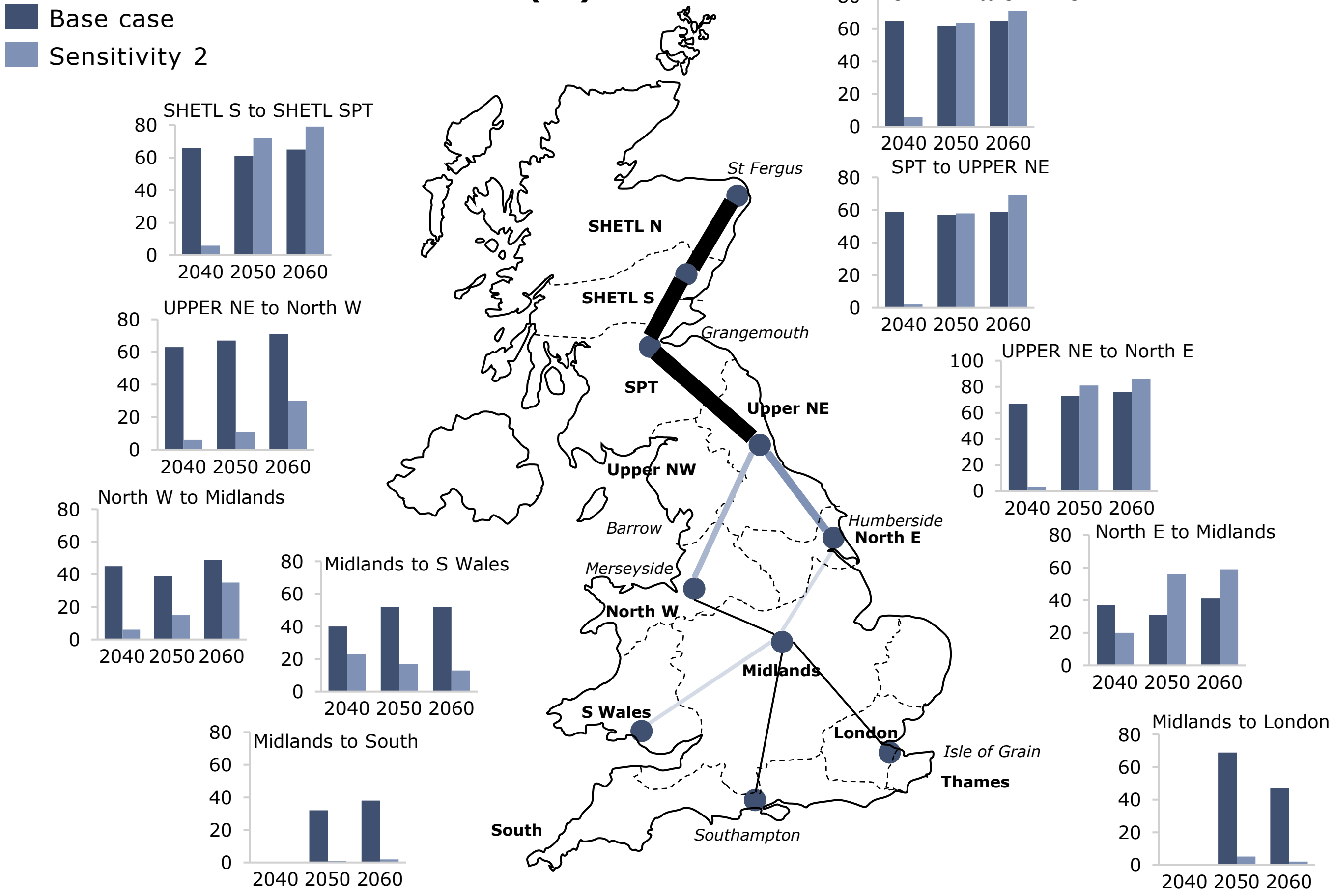



Notes: CF – Counterfactual scenario, BB – Backbone scenario. Where there is no "Sen" mentioned with CF or BB then this refers to the Base case.
* NPV is on a 35-year (2025-2060) period using a rate of 3.5% for the first 30 years and 3% for the last 5 years. **Represents % change (Sensitivity savings – Base Case savings/Base case savings)

# Overall, hydrogen backbone utilisation is lower up to the 2040s due to greater local SMR-CCS build-out driven by higher electrolyser costs

## HYDROGEN PIPES UTILISATION (%)




## COMMENTARY

- **2030-2040 period:**

  In Sensitivity 2, electrolyser build-out is delayed, as SMR-CCS remains more cost-competitive for hydrogen production well into the 2040s. This makes the backbone largely underutilised in most zones in this sensitivity until the mid-2040s.

- **2050-2060 period:**

  Electrolyser capacity begins to build up from around 2045, predominantly in Scotland, where electrolysers become more economically competitive compared to those in demand centres and southern zones. The lower electrolyser build-out in southern zones in Sensitivity 2 decreases hydrogen flows from south to north. However, the hydrogen flows from north to south increase, raising backbone utilisation from Scotland to the Midlands to supply hydrogen to CCGT $H_2$ units, that are built to replace renewable generation in those areas.

- **Southern backbone**

  The section of the backbone from the Midlands to the southern zones sees limited utilisation in this sensitivity, as these regions rely more on localised SMR-CCS hydrogen production.

# Costs in both the Counterfactual and Backbone scenarios are higher than in the Base Case, reflecting the sensitivity of results to $H_2$ production economics

**Sensitivity insights**

- Total system costs *savings* under Sensitivity 2 are lower than under the Base case, showing the impact of electrolyser costs and highlighting the impact of technology risks. Technological uncertainty around hydrogen production costs and capture performance materially affects the scale—but not the direction—of backbone benefits.
- Even with reduced capture rates, the BID3 modelling[1] preferred build out of SMR-CCS due to the higher costs of electrolysers, showing that decarbonisation can still be met, but with increased dependence on natural gas (subject to the accounting of its emissions).
- The backbone still provides limited benefits if hydrogen is in demand by allowing the connectivity of Scottish electrolysers to demand centres. If challenged by another vector, benefits will be further at risk as shown in Sensitivity 4.

**Limits of the sensitivity**

- The sensitivity draws some light on the potential impacts of the "**Technological uncertainty**" risk category
- Technology risks would impact the following modelling assumptions:
  - Technology CAPEX/OPEX *(as increased for electrolysers in the sensitivity)*
  - Hurdle rates
  - Roll out timings
  - Performance parameters such as efficiency or capture rates across hydrogen technologies *(CCS capture rates for blue hydrogen production was lowered in this sensitivity)*

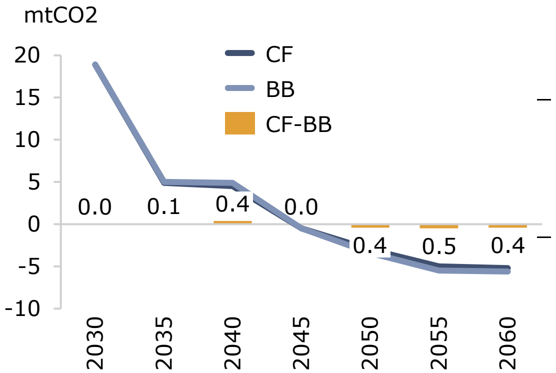
**Wider risks beyond the sensitivity**

- Delays or a slower pace to roll-out the $CO_2$ transport and storage infrastructure needed for CCS could restrict blue hydrogen production. SMR plants may also concentrate near $CO_2$ hubs, creating an uneven backbone use.
- If electrolyser costs (CAPEX/OPEX) remain high, there is a risk of prolonged reliance on SMR-CCS, slowing down learning rates for RES + electrolyser systems and delaying the transition to greater dependency on green hydrogen.
- Bottlenecks in $CO_2$ infrastructure and the high cost of electrolysers together could raise risks even further increasing total system costs and delaying supply.
- Key enabling technologies such as $H_2$ storage in salt caverns and compression systems remain at varying maturity levels. Technical uncertainties and limited deployment experience could play out as a major barrier to the backbone's deployment.

Note: 1. AFRY has used BID3, our in-house power and hydrogen market model, to develop the sensitivities. Please refer to the introduction for further notes on BID3.

# The Backbone enables limited additional electrolysis, with H₂ demand largely met by SMR-CCS, limiting emission reductions and RES curtailment

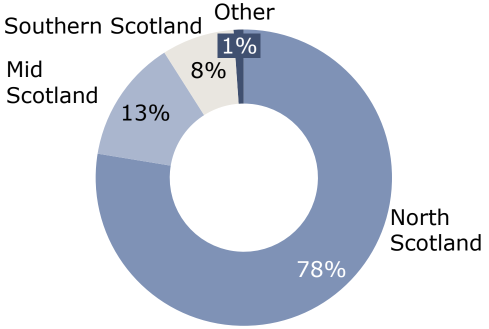
## $CO_2$ EMISSION VARIATIONS & SOCIETAL COST OF CARBON




- **2.9 mtCO2** emission savings (vs 6.6 Base case) over 35 years due to the backbone.
- **£297m NPV** (Real 2023) of social cost of carbon savings due to the backbone vs Counterfactual (vs £920m Base case)
- Under this sensitivity, the major driver of reduced emissions is the hydrogen sector which has more electrolysers in operation.

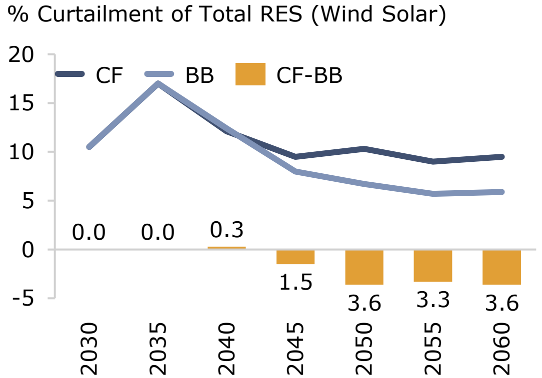
## WATER STRESS

**Regional concentration of water consumption for electrolytic $H_2$ production by 2050**



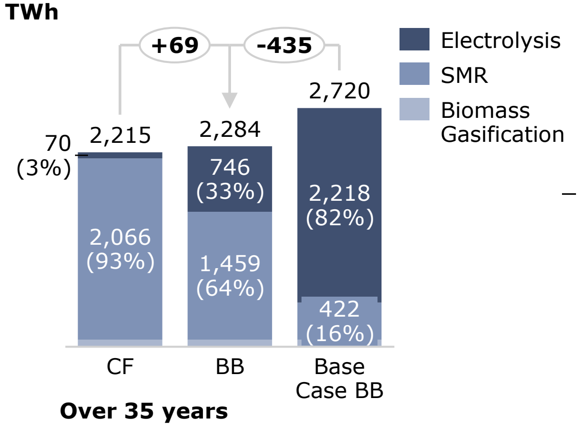

- By 2050, water use pressures as a result of green hydrogen production are concentrated mainly in Scotland with most stress being placed on northern Scotland.
- Water pressures may intensify under Sensitivity 2 due to the concentration of $H_2$ production in Northern Scotland which has existing water scarcity issues along its east coast
- South Wales was previously identified as an area of concern, but it no longer is in this sensitivity.

## RES CURTAILMENT[1]




- Across wind and solar the Backbone case has a total of **~380 TWh** of curtailment savings (vs 520TWh Base case) compared to the Counterfactual over the 35 years
- With reduced flexible demand (electrolysis) or storage, the system becomes less capable of integrating variable renewables. Therefore, less electrolysis and H₂ storage leads to higher curtailment of wind.

## HYDROGEN PRODUCTION



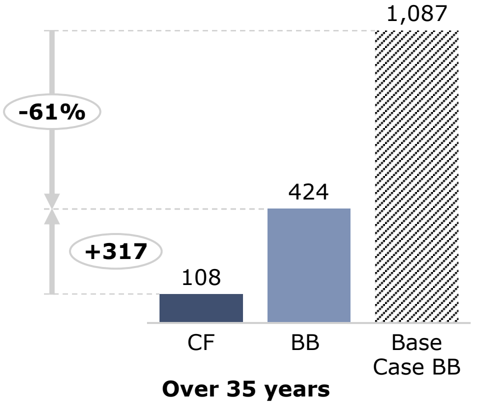

- Over the 35 years the Backbone enables an *additional* **69 TWh** (vs 167[2] TWh Base case BB-CF) of domestic production of hydrogen of which **33%** (vs 82% Base case) is electrolytic green hydrogen.
- Hydrogen production within this sensitivities BB scenario is less than the Base case by **435 TWh** in absolute terms, owing to the higher production costs of hydrogen.

1. %Curtailment = Curtailment TWh / (Generation TWh + Curtailment TWh) 2. See slide 46

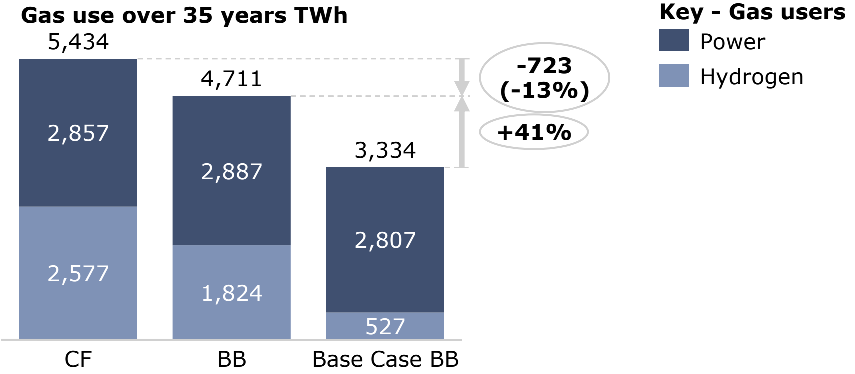
# The Backbone reduces gas use versus the Counterfactual, but lower electrolyser deployment increases exposure to gas price shocks

## POWER IMPORTS




- **317 TWh** of more power imports between the BB and CF within this sensitivity.
- Power imports drop 61% compared to the Base case owing to less electrolyser deployment in the Backbone case.
- While increased electrolysis vs the CF reduces RES curtailment by absorbing surplus generation, it also raises system electricity demand beyond curtailment periods, leading to higher net interconnector imports at the margin.
- The big divergence between the CF and BB scenarios in this sensitivity is driven by the very limited deployment of electrolysers in the CF case (<200 MW in 2050 and ~1,800 MW in 2060), compared with the BB case, which sees ~50× higher electrolyser capacity in 2050 and ~5× higher capacity in 2060.

## GAS RELIANCE




- **723 TWh** of gas use savings due to the Backbone versus the CF.
- The Backbone enables less electrolysers and relies more on SMR-CCS to produce hydrogen from natural gas compared to the Base case Backbone scenario. Consequently, natural gas demand is higher vs the Base case primarily driven by use in hydrogen production.
- As a result, the system remains more dependent on gas with the Backbone only reducing gas use by 13%. This is in contrast to the Base case where through the introduction of the backbone gas reliance dropped by 16%.
- Within this sensitivity it can be concluded that the total system cost is much more sensitive to a gas price shock.

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# Contents



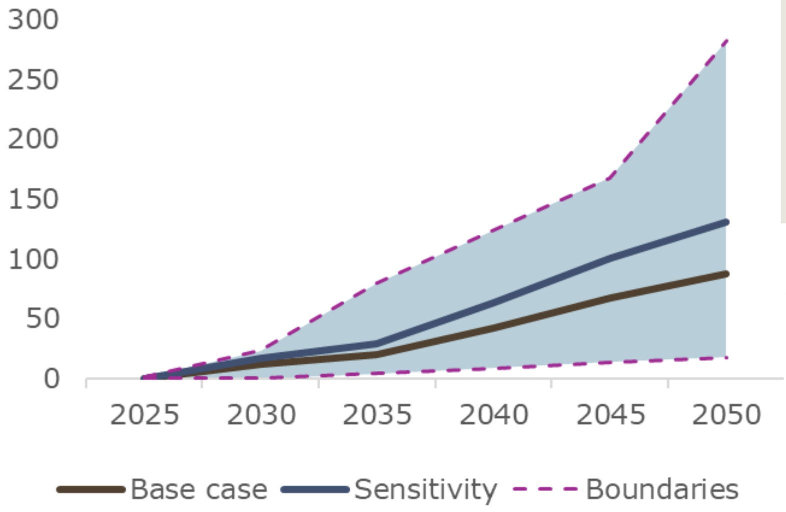


# In the hydrogen demand sensitivity, non-power hydrogen demand rises by 50% nationally, with greater distribution across zones

## STEP 1 –INCREASE NATIONAL NON-POWER $H_2$ DEMAND BY 50%

**A 50% increase in non-power hydrogen demand at national level is assumed to be a significant increase from the Base Case, while remaining within the limits of expected demand levels documented in existing literature.**

**GB non-power $H_2$ demand (TWh)**

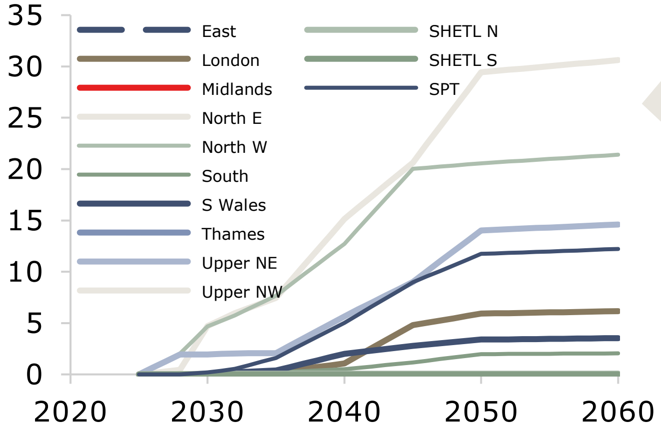



**The shaded area between the boundaries shows demand projections based on various literature sources***

## STEP 2 – DISTRIBUTE ADDITIONAL DEMAND BETWEEN ZONES

- The extra non-power hydrogen demand is spread across zones, with a greater share allocated to those that had minimal demand in the Base case. This approach assumes that regions without traditional hydrogen demand from industrial activities might utilise the backbone to support new industrial developments.
- Additional demand is only introduced once the corresponding backbone branch is operational, preventing the creation of isolated clusters with stranded hydrogen production facilities.

**GB non-power $H_2$ demand by zone (TWh)**



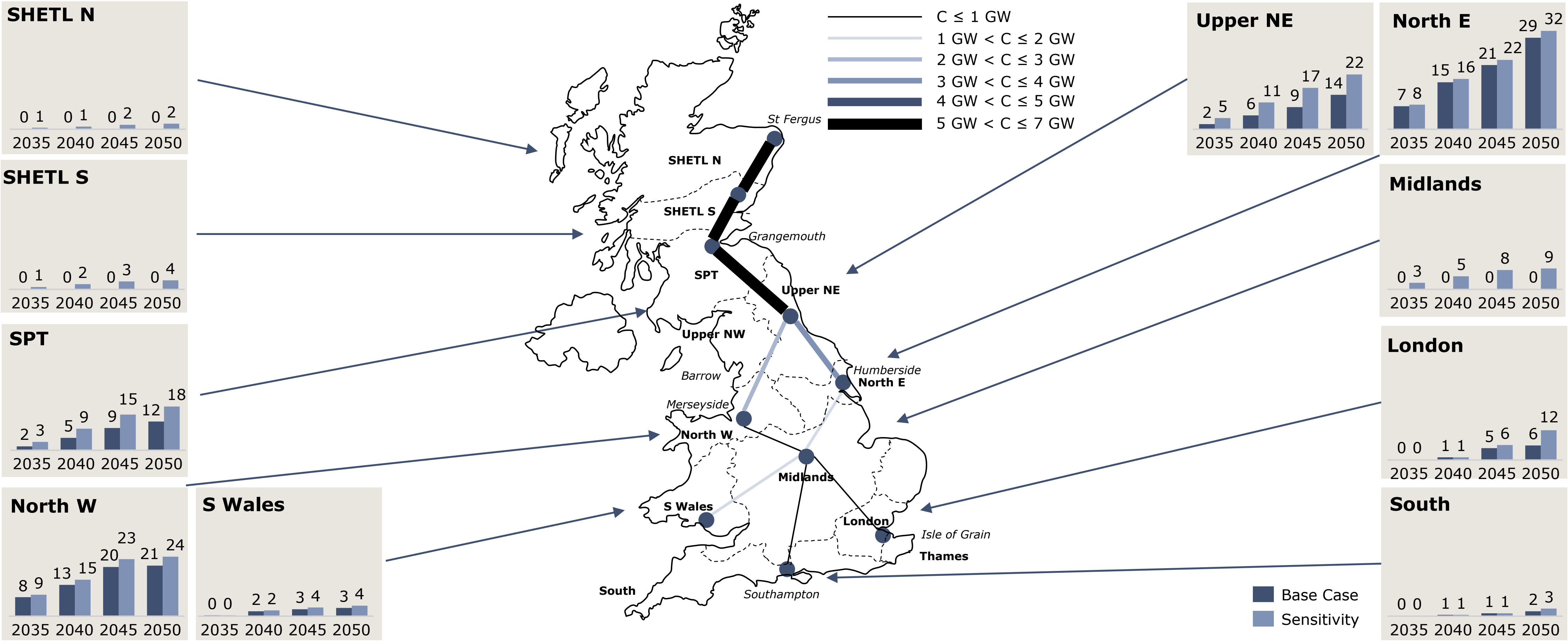

**In this sensitivity, the current $H_2$ clusters of North E and North W still have the highest demand. However, other zones such as Midlands, London, SPT, and Upper North E have considerably more demand compared to the Base case.**

*Sources in literature: CB6 – Balanced Net Zero Pathway, CB6 – Headwinds, CB6 – Tailwinds, CB6 – Widespread Engagement, CB6 – Widespread Innovation, FES 2024 – Hydrogen Evolution, FES 2024 – Holistic Transition, FES 2024 – Electric Engagement, FES 2024 – Counterfactual, DESNZ – High, DESNZ – Central, DESNZ – Low, CB7 – Balanced Pathway, FES 2024

PART 2 | SENSITIVITY 3 - HIGHER NON-POWER $H_2$ DEMAND

# Largest non-power hydrogen demand increases occur in Upper NE and Midlands; Shetl N, Shetl S zones move from zero to measurable demand

## NON-POWER HYDROGEN DEMAND (TWH)




Note: The backbone configuration shown is for 2050 and will remain consistent in both the Sensitivity and Base cases.

# Higher non-power hydrogen demand in Sensitivity 3 leads to significant build-out of SMR-CCS in southern zones and more electrolysers in Scotland

| KEY STORYLINES | |
|---|---|
| **1** | **Hydrogen production:** There is a higher electrolyser build-out to meet the additional hydrogen demand; however, the increase is relatively modest, around +12% in CF and +14% in BB compared to their respective Base cases. There is also significant SMR-CCS capacity build-out (3.1 GW vs 7 GW in BB and 7.1 GW vs 11.9 GW in CF in 2060), predominantly to meet the additional hydrogen demand in London, the Midlands, the North, and the South. Given the substantially higher share of flat non-power hydrogen demand, and the absence of salt cavern storage in the Midlands, London, and South Wales, SMR-CCS proves to be a more economical option for meeting this flat demand compared to building the necessary infrastructure required for electrolytic hydrogen production. |
| **2** | **Hydrogen storage:** In the sensitivity cases, the extra hydrogen demand in Scotland is mainly fulfilled by electrolytic production, leading to a notable rise in hydrogen storage tanks. Under the BB case for Sensitivity 3, the expanded storage capacity results in higher pipeline utilisation, whereas in the CF sensitivity, the additional storage is necessary to satisfy the increased local non-power hydrogen demand. In the BB Sensitivity 3 scenario, there is a marginally greater development of salt cavern storage capacity in the Northwest and South regions compared to the Base case, which is aimed at accommodating the increased hydrogen demand by optimising the hydrogen backbone network. |
| **3** | **Dispatchable generation:** The overall capacity build of dispatchable generation in the sensitivity cases remains largely unchanged from the Base cases. |
| **4** | **Electricity transmission network:** There is slightly less network reinforcement in both CF and BB sensitivities compared to their respective Base cases, due to the system being more reliant on hydrogen storage and SMR-CCS. |
| **5** | **Renewables:** In the BB Sensitivity 3 scenario, onshore wind capacity increases in Midlands compared to its Base case. This increase is intended to facilitate the deployment of electrolysers to satisfy the additional non-power hydrogen demand. |

CF: Counterfactual case. BB: Backbone case

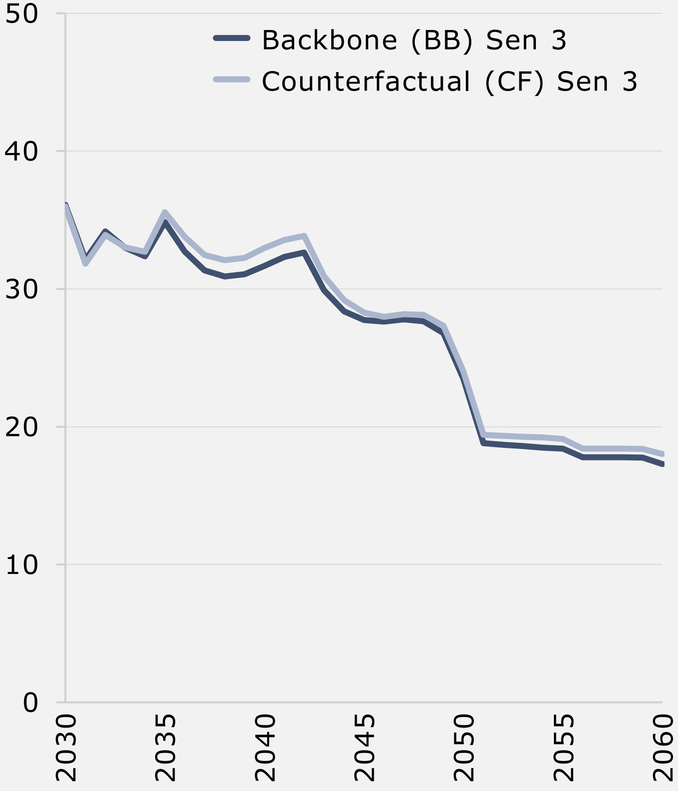
# In this case, backbone cost savings slightly grow with higher non-power hydrogen demand, but the overall economic benefit is still limited

## KEY MESSAGES

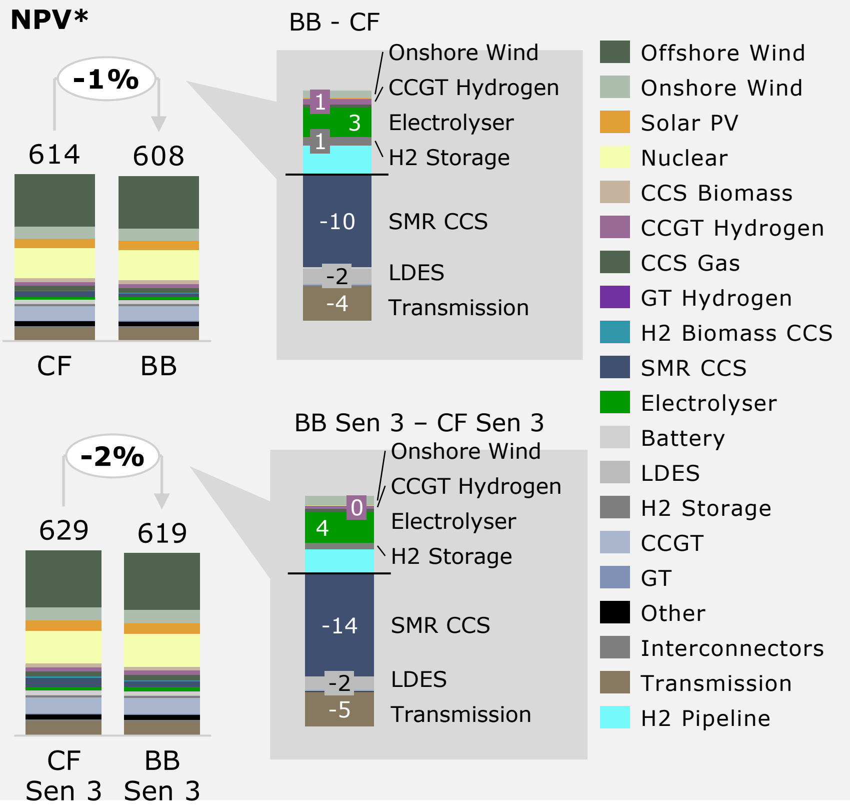
| | |
|---|---|
| **1** | Total system costs under Sensitivity 3 rise in both the BB and CF cases relative to the Base cases, reflecting the increased capacity expansion needed to satisfy the additional demand. |
| **2** | Cost savings in this sensitivity are about 67%** greater than the Base case, which is closely correlated to the 50% increase in total hydrogen demand. This suggests that a scenario with higher hydrogen demand could result in greater cost savings by having the hydrogen backbone in place. |
| **3** | Net savings from the backbone in the sensitivity rise from £6 bn to £10 bn in NPV terms. The higher savings in Sensitivity 3 compared to the Base case stem from higher SMR build-out and generation in the sensitivity CF and slightly lower transmission reinforcement required in the Sensitivity BB scenario. |
| **4** | Despite those additional savings in the sensitivity, the cost benefit remains marginal relative to the total system cost. However, this estimate may be conservative as the backbone has not been re-optimised or expanded to accommodate this additional demand. |

## SENSITIVITY 3 SYSTEM COST COMPARISON

ANNUAL SYSTEM COST (BN £, REAL 2023)




TOTAL SYSTEM COST BY TECHNOLOGY (BN £, REAL 2023)

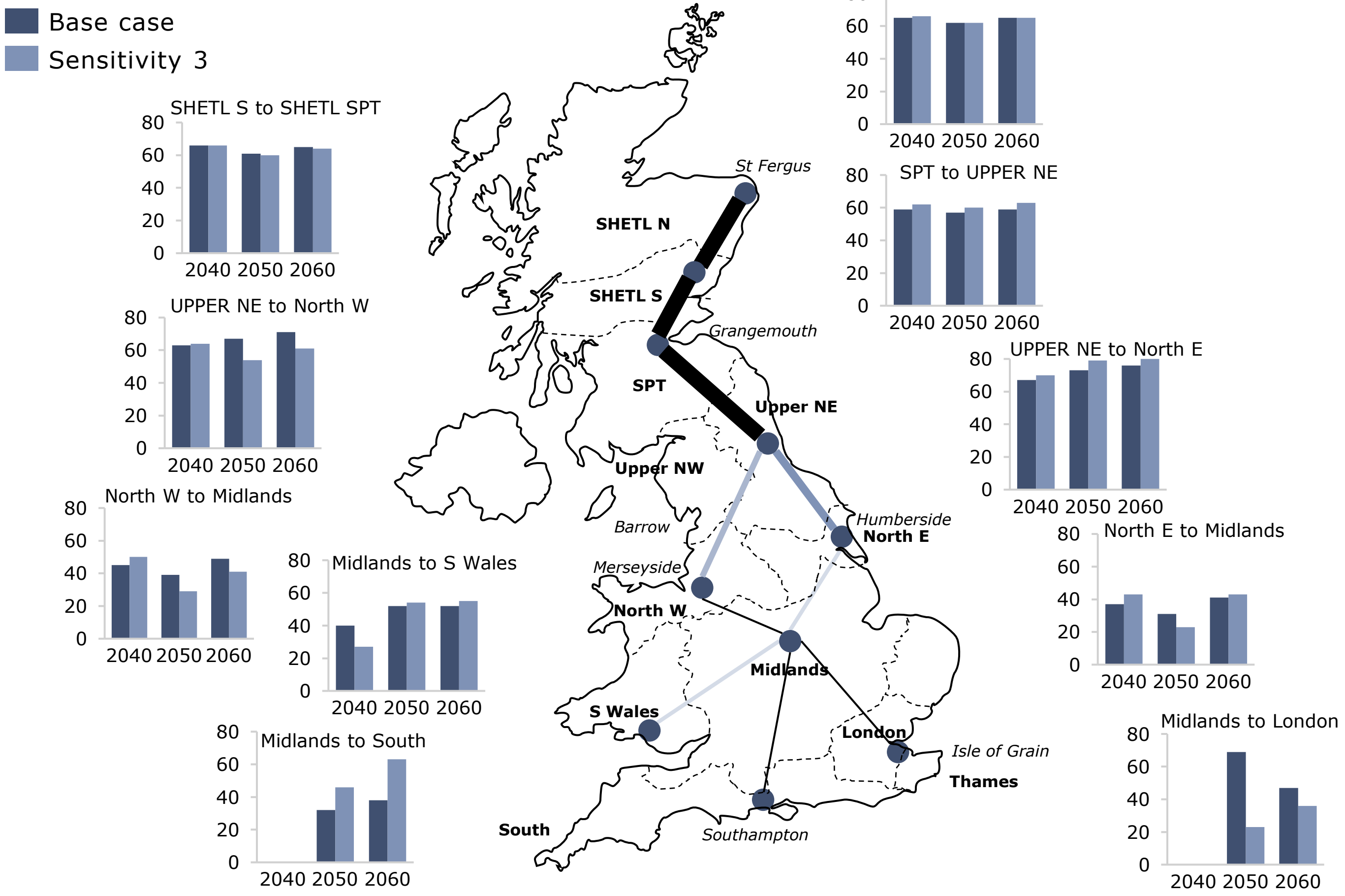



Notes: CF – Counterfactual scenario, BB – Backbone scenario. Where there is no "Sen" mentioned with CF or BB then this refers to the Base case.
* NPV is on a 35-year (2025-2060) period using a rate of 3.5% for the first 30 years and 3% for the last 5 years. **Represents % change (Sensitivity savings – Base Case savings/Base case savings)

# Backbone utilisation rises in some areas and falls in others, influenced by factors such as regional shares of non-power $H_2$ demand and production technology

## HYDROGEN PIPES UTILISATION (%)




## COMMENTARY

- **Scotland – Northeast backbone**
- In Sensitivity 3, there is a greater build-out of electrolysers and hydrogen storage tanks in Scotland to meet the additional hydrogen demand. Hydrogen flows from Scotland to Northeast England remain similar to the Base case.
- However, flows in the other direction (i.e. Northeast England to Scotland), which were negligible in the Base case, increase significantly during certain periods to meet Scotland's non-power hydrogen demand, leading to higher backbone utilisation between certain boundaries.
- **Southern backbone**
- The southern zones present a mixed picture, with some pipelines showing increased utilisation and others reduced utilisation. Flows from the Midlands to the South increase to meet the hydrogen demand in the South.
- The London zone relies on local SMR-CCS production to meet its hydrogen demand, and as a result, flows along the Midlands-to-London pipe of the backbone decrease.

# The sensitivity highlights the materiality of demand on the effectiveness of the Backbone to deliver benefits in a coordinated ecosystem

**Sensitivity insights**

- Higher hydrogen demand means more supply requirements which means the system costs have increased relative to the Base case.
- The backbone enables benefits compared to the Sensitivity 3 CF which is also marginally more than the benefits provided within the Base case.
- This sensitivity displays the greatest benefits (£10 Bn NPV terms) as a result of the backbone compared to other sensitivities.
- This study adopts conservative assumptions for demand based on the lower end of estimates in the literature in the Base case.

**Limits of the sensitivity**

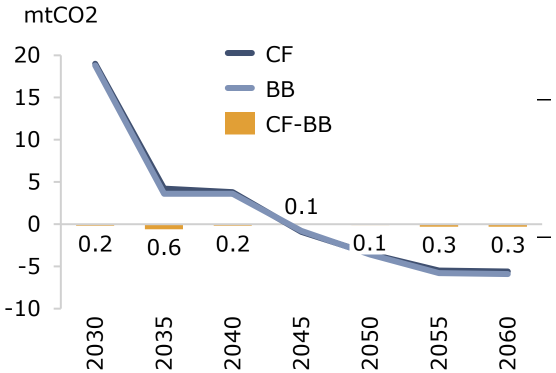
- The sensitivity draws some light on the potential impacts of the "**Demand Uncertainty**" risk category
- Demand uncertainty would impact the following modelling assumptions:
  - Power and non power hydrogen demand growth trajectories *(in this sensitivity non power hydrogen demand is increased only)*
  - Geographic distribution of non-power hydrogen demand *(In this sensitivity, extra non-power hydrogen demand is unevenly distributed but results in a more even overall distribution when combined with the base case).*

**Wider risks beyond the sensitivity**

- If supply and demand do not scale up in step with the backbone build-out, the infrastructure could become a bottleneck, limiting the benefits of the backbone.
- Conversely, uneven or delayed policy implementation across sectors could slow demand uptake, leading to under-utilised assets. Competing vectors—such as electrification, biofuels, or CCUS—could further reduce hydrogen demand and impact investment recovery.
- Electrolyser deployment must be matched by RES and grid expansion. To satisfy short-term demand pressures, policy may drive suboptimal or poorly located projects which would be in contradiction to a national strategic program, locking in long-term inefficiencies.

# This sensitivity delivers greater carbon cost savings and enables more $H_2$ production, putting greater stress on regions with existing scarcity issues

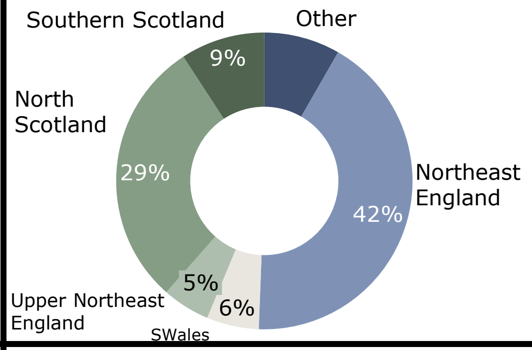
## $CO_2$ EMISSION VARIATIONS & SOCIETAL COST OF CARBON




- **7.4 mtCO2** emission savings (vs 6.6 Base case) over 35 years due to the BB.
- **£1,163m NPV** (Real 2023) of societal cost of carbon savings due to the backbone vs Counterfactual (vs £920m Base case)
- The emission savings can be traced back to an increase in electrolyser deployment vs SMR-CCS due to the backbone.

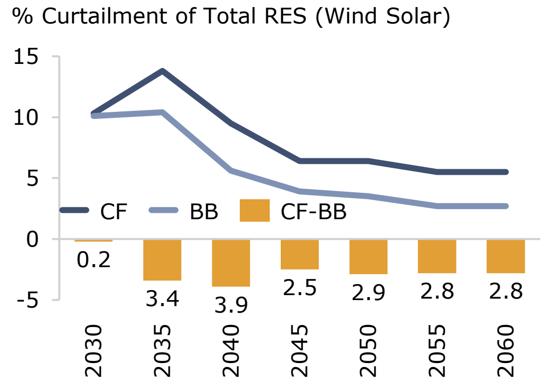
## WATER STRESS

**Regional concentration of water consumption for electrolytic $H_2$ production by 2050**



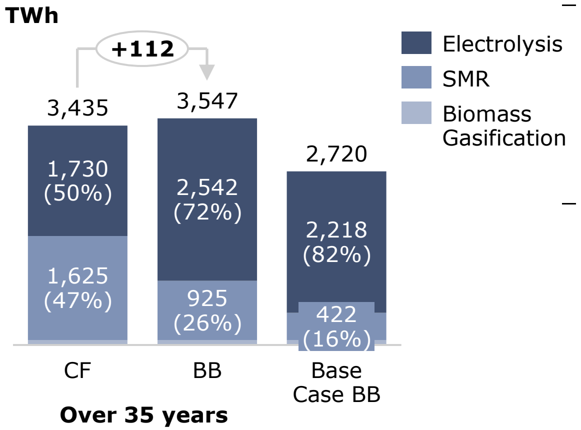

- Under both the Base case and this sensitivity, northern Scotland and south Wales are an area of concern due to existing water scarcity issues.
- Northeast England is a region experiencing significant water needs in this sensitivity; however, water scarcity is not currently a concern within the boundaries outlined in this report. In contrast, the Midlands—an area bordering this region—remains a point of concern.

## RES CURTAILMENT[1]




- Across wind and solar the Backbone case has a total of **~542 TWh** of curtailment savings (vs 520 TWh Base case) compared to the Counterfactual over the 35 years
- Curtailment improves vs the Base case scenarios due to greater electrolyser build out.

## HYDROGEN PRODUCTION




- Over the 35 years the backbone enables an *additional* **112 TWh** (vs 167[2] TWh Base case BB-CF) of domestic production of hydrogen of which **72%** (vs 82% Base case) is electrolytic green hydrogen.
- Electrolyser capacity expands to meet additional $H_2$ demand. SMR-CCS sees substantial build-out in southern regions as the most cost-effective solution for supplying steady, non-power hydrogen demand in the absence of large $H_2$ Storage assets.

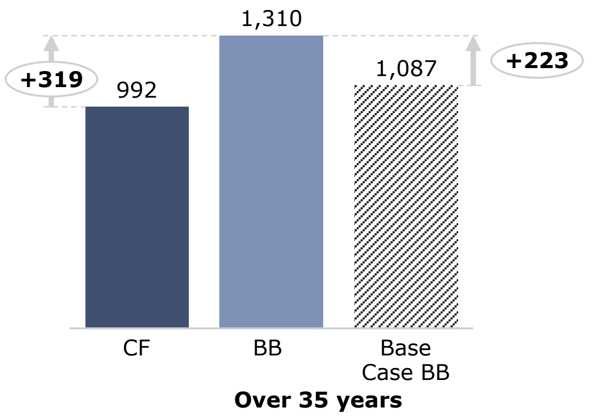
1. %Curtailment = Curtailment TWh / (Generation TWh + Curtailment TWh) 2. see slide 46



AFRY

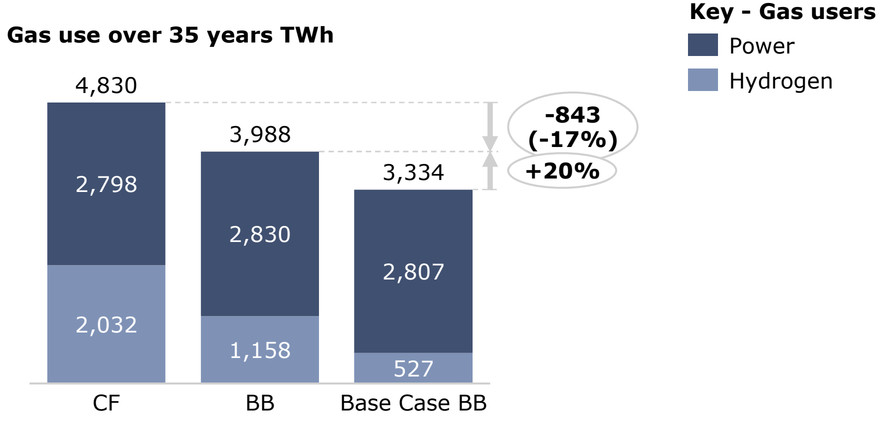
# The Backbone relies more on power imports and gas than the Base Case but less on gas than the Counterfactual

## POWER IMPORTS




- **319 TWh** of more power imports between the BB and CF within this sensitivity.
- Power imports follow the same logic as in the Base case where they have increased as a result of introducing the backbone.
- More electrolysers on the system means more imports of power.
- In the BB case, electrolysers provide flexibility while absorbing cheap power, reducing export opportunities as electricity that would have been exported in the CF is instead used domestically for $H_2$. Conversely, when renewable output is low, GB may import more to sustain electrolyser demand.

## GAS RELIANCE AND RESILIENCE




- **842 TWh** of gas use savings due to the Backbone versus the CF
- The Backbone enables more electrolysers and relies less on SMR to produce hydrogen from natural gas. Consequently, natural gas demand is lower vs its counterfactual.
- However, compared to the Base case BB scenario there is significantly more natural gas demand driven almost solely by blue hydrogen production. The larger non-power hydrogen demand has forced greater SMR-CCS build out in certain regions where electrolysers are not feasible.
- The Backbone scenario for this sensitivity would result in greater reliance on natural gas and so as a result, the system is more sensitive to gas price shocks compared to the Base case BB scenario. However, comparing the BB with the CF within this sensitivity gas reliance and so gas price shock sensitivity drops.

# Contents



# Sensitivity 4 assesses system cost changes if biomethane replaces hydrogen as a fuel in power

**Impact on system cost methodology**

- Biomethane could replace hydrogen in the power sector; Sensitivity 4 assesses a scenario where it fully does so.
- The sensitivity was developed by:
  - Replacing hydrogen in power generation with biomethane.
  - Applying biomethane cost assumptions.
  - Adjusting CAPEX and fixed OPEX for relevant technologies to reflect changes in hydrogen demand.
- These adjustments were applied to both the Base Case CF and BB scenarios to create this sensitivity. More information on our cost estimates can be found in Annex 2, as well as more context on biomethane.
- The GB biomethane sector is assessed by comparing production potential from the UK Green Gas Task Force with AFRY forecasts, examining feedstock impacts on price, and using a production cost curve to evaluate system cost implications when biomethane replaces hydrogen in power generation.
- The scenario assumes zero carbon intensity, though it could be lower with increased use of carbon-negative feedstock.
- This sensitivity assumes biomethane can fully replace hydrogen in the power sector, though other sectors may compete for biomethane and be willing to pay more, potentially taking priority.
- Based on the above assumption, total hydrogen demand in each region of Great Britain (England, Wales, Scotland) decreases by the amount of hydrogen consumed in the power sector
- The cost of using biomethane as a power generation fuel is based on the biomethane production cost curve which is added to the system cost, with adjustments made for any anticipated efficiency variations between the thermal generators of the two technologies (CCGT and CCGT $H_2$).
- CAPEX and fixed OPEX for technologies such as CCGT $H_2$, hydrogen storage, electrolysers, SMR-CCS, $H_2$ backbone, solar PV, and wind are adjusted based on changes in hydrogen demand.
- Biomethane emissions vary by feedstock, but this sensitivity assumes zero emissions.

Note: Additional details about biomethane are available in the annex.

# The economic justification for maintaining a backbone remains mostly unchanged under the biomethane sensitivity

## KEY MESSAGES

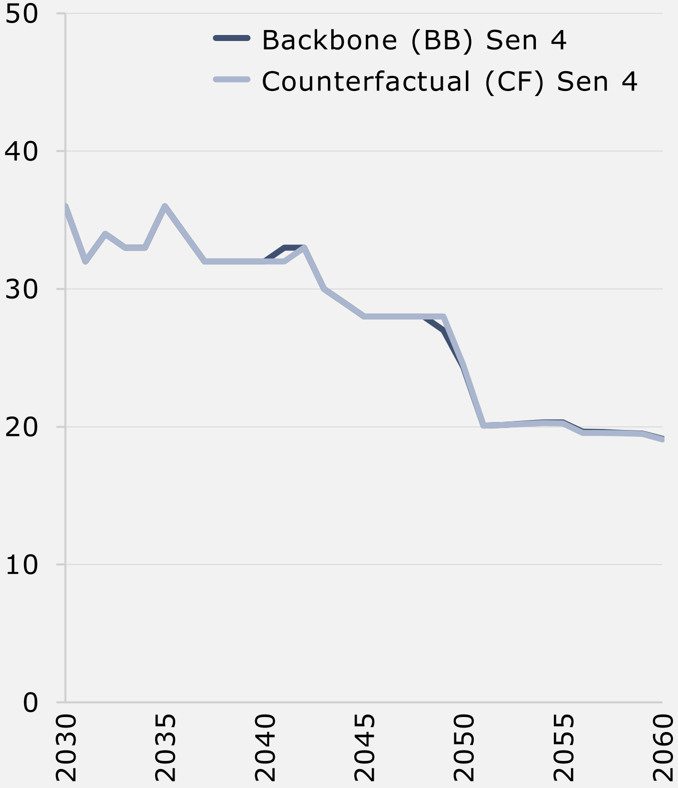
1. In the biomethane sensitivity, both cases remain closely aligned on total annual system costs through 2060 and on NPV.

2. The Sensitivity 4 backbone case's NPV remains at the same marginal difference of 1% lower than that of the Counterfactual case in the sensitivity. This suggests that even if it is assumed that biomethane fully replaces hydrogen demand in the power sector, it does not materially impact the economic justification for the backbone.

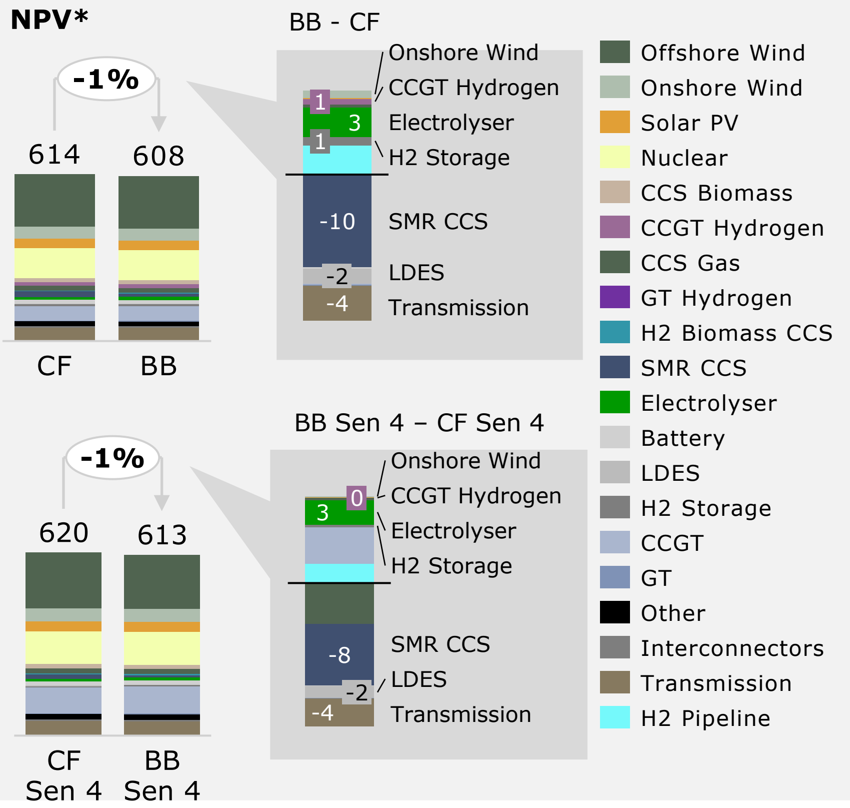
3. Both sensitivity cases (BB and CF) have shown a minor increase in NPV compared to their corresponding Base cases. This outcome is driven by the higher variable costs associated with using biomethane as a fuel, which outweigh the cost reductions related to the hydrogen infrastructure needed to meet the equivalent electricity demand.

## SENSITIVITY 4 SYSTEM COST COMPARISON

ANNUAL SYSTEM COST (BN £, REAL 2023)




TOTAL SYSTEM COST BY TECHNOLOGY (BN £, REAL 2023)

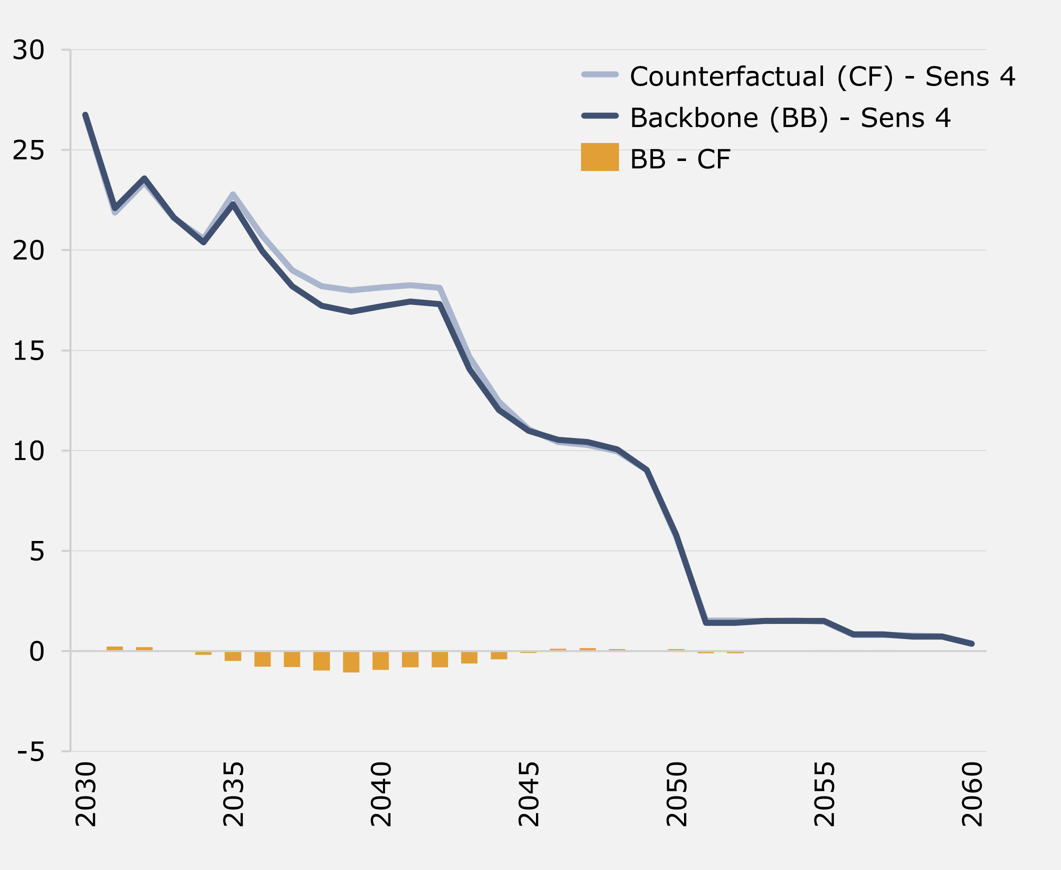



Notes: CF – Counterfactual scenario, BB – Backbone scenario. Where there is no "Sen" mentioned with CF or BB then this refers to the Base case.
* NPV is on a 35-year (2025-2060) period using a rate of 3.5% for the first 30 years and 3% for the last 5 years

# In the sensitivity, incorporating the backbone results in a comparable decrease in mid-term CAPEX expenditure, similar to the Base cases

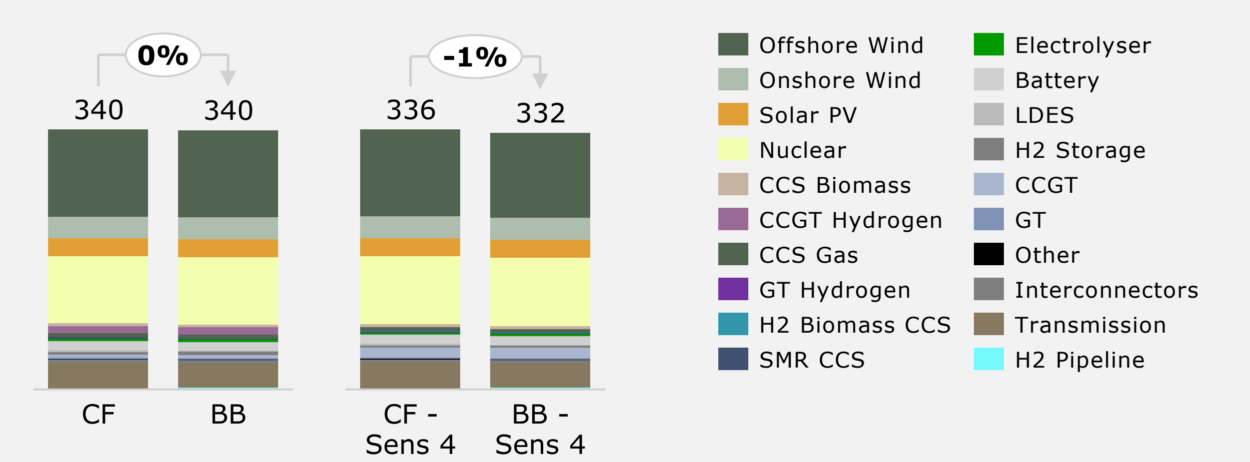
## ANNUAL CAPEX (BN £, REAL 2023)




## COMMENTARY

- As with the Base case, the sensitivity analysis shows that the gap in capital expenditure between the two scenarios stays relatively minor in both the short term (early 2030s) and the long term. In the medium term, the difference is somewhat greater than in the Base cases, albeit .small in absolute terms
- In the sensitivity analysis, the Backbone scenario has a lower NPV compared to the Counterfactual scenario, while in the Base cases, both were equal
- The CAPEX reduction in sensitivities results from decreased capacity in hydrogen storage, pipeline network, electrolysers, SMR-CCS, RES, and switching CCGT $H_2$ to CCGTs.

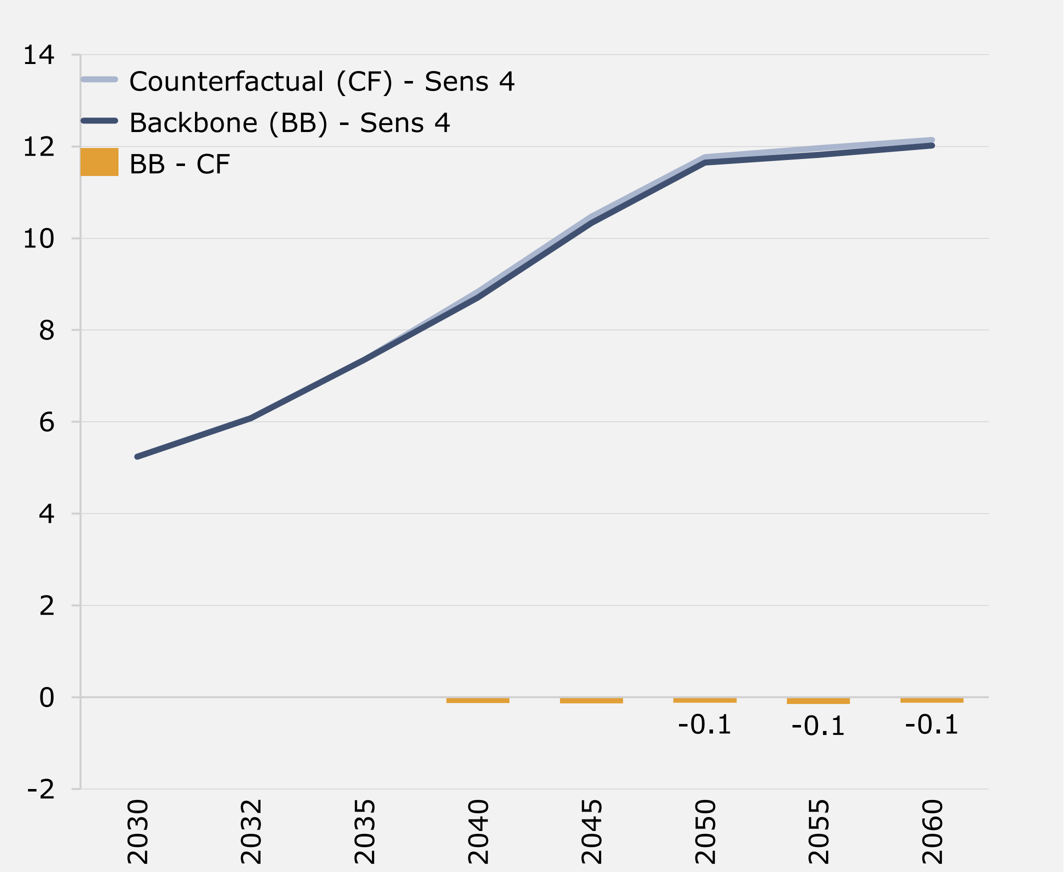
## NPV[1] OF CAPEX BY TECHNOLOGY (BN £, REAL 2023)




Notes: 1 – NPV is on a 35-year (2025-2060) period using a rate of 3.5% for the first 30 years and 3% for the last 5 years

# Fixed OPEX is slightly lower in Sensitivity 4 with the backbone due to lower hydrogen technology capacities than in the base cases

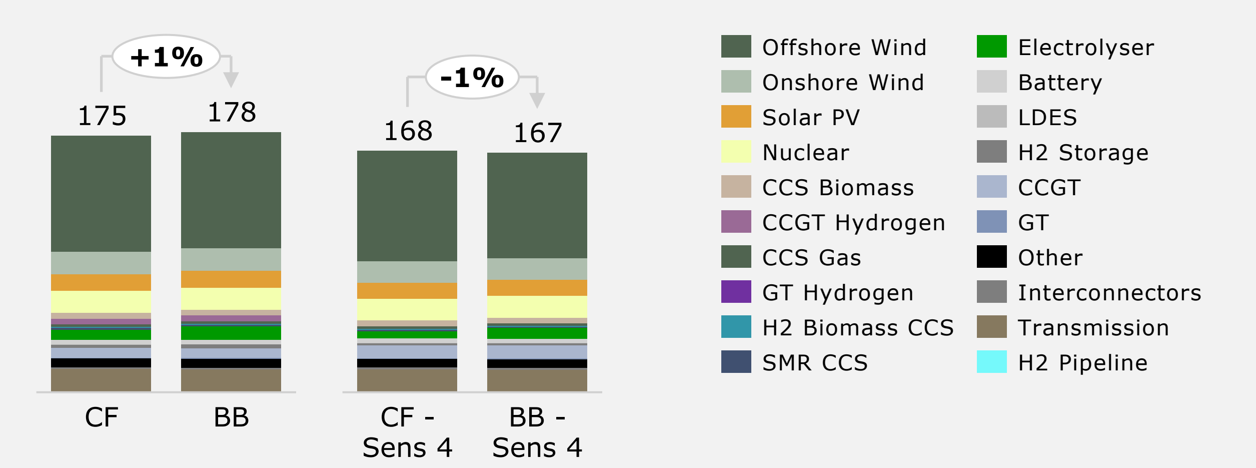
## ANNUAL FIXED OPEX (BN £, REAL 2023)




## COMMENTARY

- Fixed and variable OPEX refer to two different ongoing costs associated with running assets. Fixed OPEX are costs that do not change with the amount of electricity or hydrogen produced or transported, so are incurred regardless of utilisation levels
- Unlike the Base cases, where Fixed OPEX was slightly greater in the Backbone case, in Sensitivity 4 analysis the Counterfactual case shows a marginally higher value, although the overall difference between the two cases remains minimal.
- The change from the Base cases is primarily driven by the decreased capacity in hydrogen storage, pipeline network, electrolysers, SMR-CCS, RES, and switching CCGT $H_2$ to CCGTs.

## NPV[1] FIXED OPEX BY TECHNOLOGY (BN £, REAL 2023)

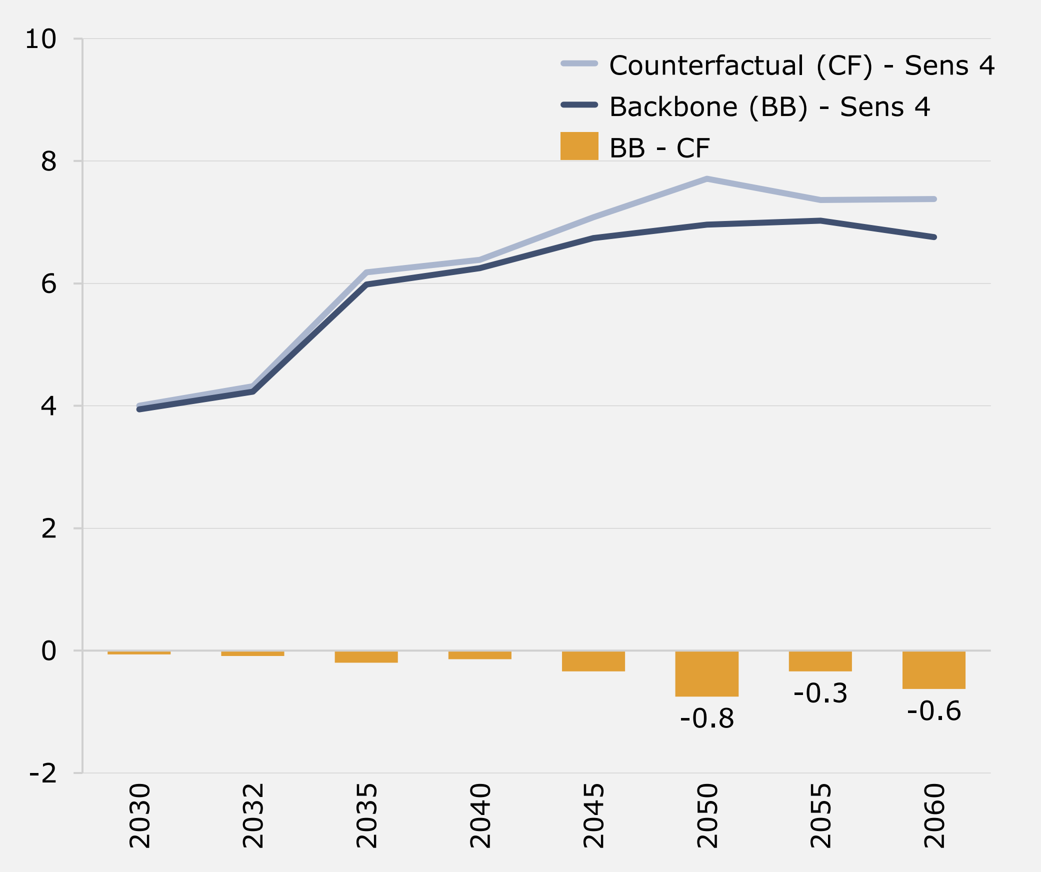



Notes: 1 – NPV is on a 35-year (2025-2060) period using a rate of 3.5% for the first 30 years and 3% for the last 5 years

# In Sensitivity 4, biomethane increases variable OPEX in both the Backbone and Counterfactual, with little change in the cost differential

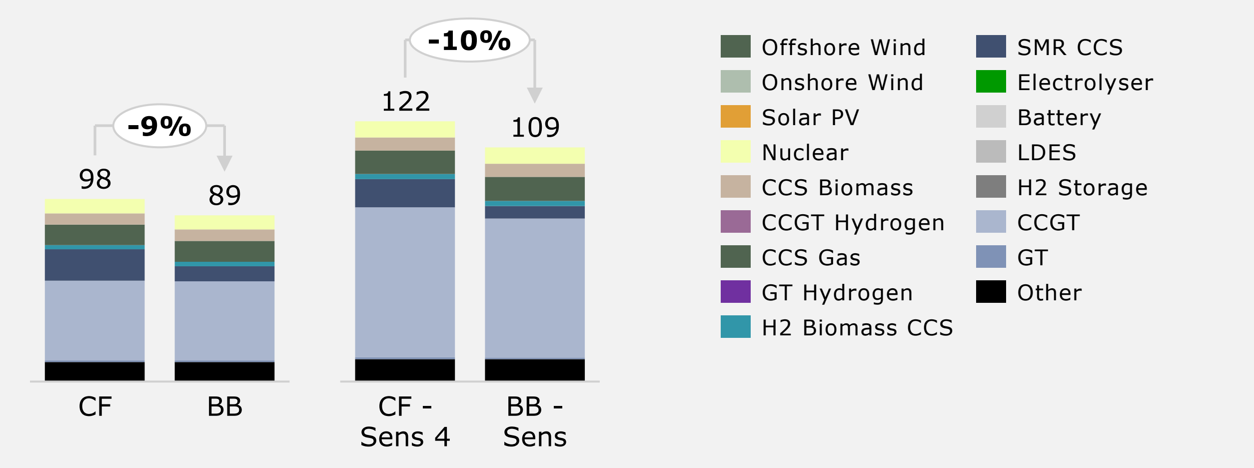
## ANNUAL VARIABLE OPEX (BN £, REAL 2023)




## COMMENTARY

- Variable OPEX can be disaggregated into two key components: 1) fuel and variable other works costs (VOWC), and 2) carbon costs, both of which vary throughout the year, depending on the operation of the asset in question.
- In the sensitivity, the variable OPEX of the system remains lower in the Backbone scenario compared to the Counterfactual.
- In both sensitivity cases, the NPV of variable OPEX increases relative to their respective Base cases. This rise is attributed to the use of biomethane as a fuel and the associated additional costs.

## NPV[1] VARIABLE OPEX BY TECHNOLOGY (BN £, REAL 2023)




Notes: 1 – NPV is on a 35-year (2025-2060) period using a rate of 3.5% for the first 30 years and 3% for the last 5 years

# Risks emerge when biomethane and hydrogen pathways evolve without coordinated policies or a unified vision

**Sensitivity insights**

- A parallel biomethane–hydrogen system can offer flexibility, resilience, and optionality by leveraging existing gas infrastructure and diverse feedstocks - if intentionally designed.
- Sensitivity 4 reflects a world where dual tracks are well-optimised and aligned. If this coordination fails, additional risks emerge that could erode the backbone's benefits.

**Limits of the sensitivity**

- The sensitivity draws some light on the potential impacts of the "**Public Acceptability**", "**Demand Uncertainty", "Regulatory and policy uncertainty" and "technological uncertainty"** risks**.**
- It touches on public acceptability by leveraging existing gas infrastructure, demand uncertainty with potential for demand substitution in power generation, and regulatory and technology risk by enabling a dual-track approach across the two vectors.
- Within the sensitivity biomethane has replaced power hydrogen demand however non power hydrogen demand remains unchanged from the Base case. Hydrogen demand in non-power applications could also be replaced with biomethane.
- It does not allow for the use of biomethane for hydrogen production – e.g. SMR + biomethane.

**Wider risks beyond the sensitivity**

- If biomethane adoption outpaces hydrogen, the hydrogen backbone could become underused and economically unjustified.
- Running two parallel gas systems erodes economies of scale for hydrogen infrastructure.
- Uncertainty over which vector will prevail may delay private sector commitments, limiting early hydrogen backbone use.
- Pursuing both fuels divides policy focus and incentives, creating unclear market signals for investors. Split attention and capital can slow overall decarbonisation.
- Biomethane can rely on existing gas assets, and as a result this could delay the potential repurposing of gas pipelines for hydrogen, which could reduce pipeline costs. The suitability and timing of switches in existing pipelines to hydrogen will be location-specific and needs coordination with the building of new hydrogen pipelines and overall gas network planning.

AFRY

# Contents





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# In all sensitivities, the backbone's economic impact stays relatively consistent, showing it does not hugely influence the total system cost

**SENSITIVITIES**

**Sensitivity 1 - Reduced & delayed hydrogen backbone**

- Reducing and delaying the hydrogen backbone does not materially impact the economic case for having a backbone compared to scenarios without it.
- Nonetheless, the absence of the backbone in certain areas influences the competitiveness and capacity deployment of some technologies, especially those related to hydrogen production and storage.

**Sensitivity 2 - CCS capture rate for blue hydrogen production & higher electrolyser costs**

- Higher electrolyser costs and lower SMR-CCS capture rates have minimal impact on the economic justification of the backbone, aligning with the Base case.
- Technological uncertainty around hydrogen production costs and capture performance materially affects the scale—but not the direction—of backbone benefits. The backbones economic value is exposed to under-performance in hydrogen production technologies—particularly electrolyser costs.

**Sensitivity 3 – Higher non-power $H_2$ demand**

- The higher demand for non-power hydrogen marginally enhanced the cost savings associated with the backbone, although the overall economic advantage remains limited.
- The economic value of the backbone might be improved by re-optimizing or expanding the network to better handle this increased demand.

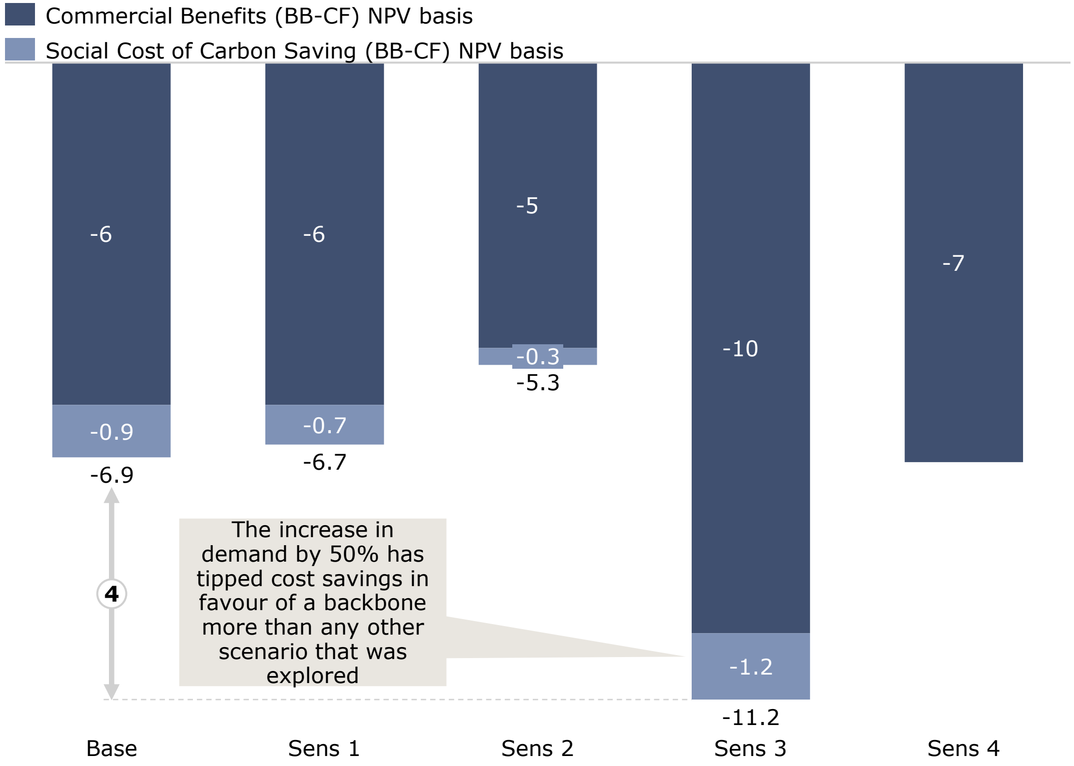
**Sensitivity 4 – Biomethane in the power sector**

- The economic justification for maintaining a backbone remains mostly unchanged (<1% in NPV terms) even if it is assumed that biomethane fully replaces hydrogen in the power sector.
- However, the overall system cost in both cases, with and without the backbone, rises compared to the Base case because the variable costs linked to using biomethane as fuel exceed the savings from a reduced hydrogen related infrastructure required to satisfy the same electricity demand.

# A 50% increase in non-power hydrogen demand tips significantly cost savings in favour of the backbone—more so than in any other sensitivity

## TOTAL SYSTEM COSTS BENEFITS (BB-CF) NPV BN £, REAL 2023




***Negative values show savings because of the BB***
***All values are the result of the difference between the BB case and the CF with respect to each scenario***

| Sensitivity | Key messages |
|---|---|
| **1.Delayed & reduced backbone** | – A minimal reduced scope BB can deliver the same benefits over the modelled period in aggregate as long as the main branches (Scotland to Humberside and Merseyside) are in place in a timely fashion |
| **2.Higher electrolyser costs & lower capture rates for blue hydrogen** | – Higher electrolysis costs shift supply toward SMR-CCS, so the backbone enables only limited—and more expensive—electrolysis, resulting in the lowest system cost savings. |
| **3.Higher non-power $H_2$ demand – (greater regional spread)** | – Out of all sensitivities, system cost savings are greatest due to the BB serving a more distributed demand and expanded non-power demand. The system cost savings are highest vs the CF at ~2%.<br>– The BB enables optimisation, avoids overbuild and demand centres benefit from lower-cost $H_2$ via the BB.<br>– Benefits vary by zone. In some zones, local SMR-CCS is more efficient, reducing pipeline use. |
| **4. Biomethane replacing hydrogen in power** | – The backbone's savings in the sensitivity mainly stem from lower variable OPEX, as biomethane is costlier while the backbone further reduces hydrogen fuel costs.<br>– A coordinated twin-track approach could still unlock marginal system-wide benefits. |

Backbone optimisation was only performed for the base case. It is therefore reasonable to assume that, had Sens. 2 also been iterated, pipeline capacities would have been reduced further relative to the base case, yielding slightly higher savings.



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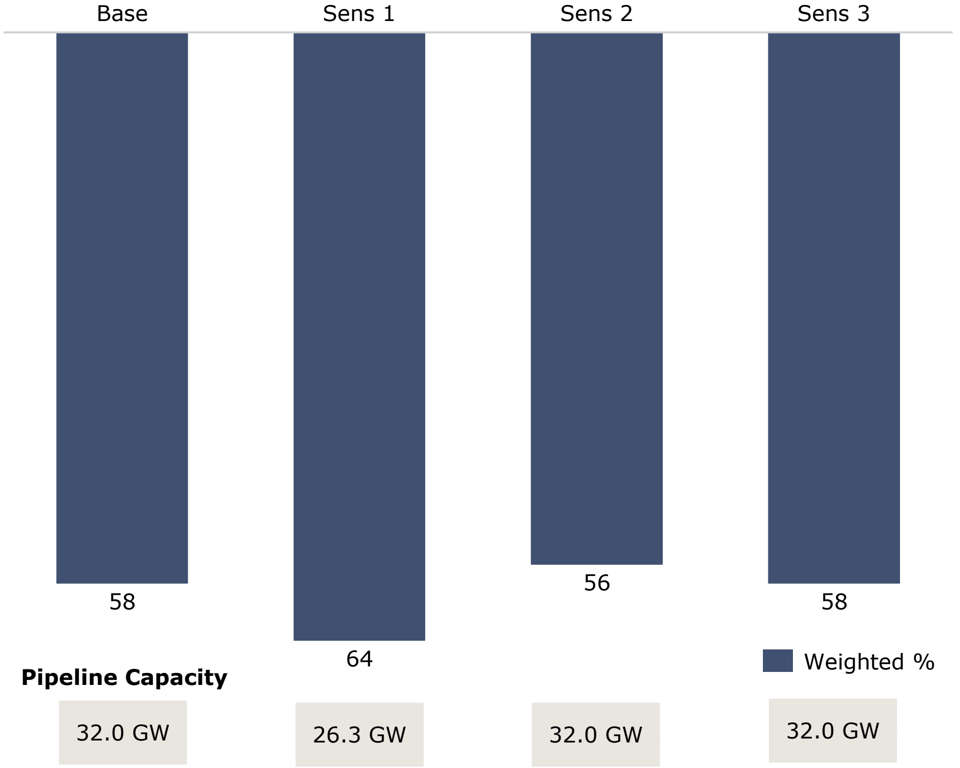
# The pipeline utilisation across the sensitivities shows that reducing the pipeline build-out to the northern zones leads to higher utilisation in 2050

## CAPACITY WEIGHTED AVERAGE PIPELINE UTILISATION, 2050 (%)




***Sensitivity 1 has the highest pipeline utilisation; this may be due to its lower capacity build out***

| Sensitivity | Key messages |
|---|---|
| **1.Delayed & reduced backbone** | – Reducing the backbone capacity build-out leads to a more concentrated use of the available pipeline capacity for hydrogen transport between zones. The resulting increase in capacity-weighted average utilisation mainly reflects the removal of under-utilised capacity, leaving only the more actively used parts of the network. |
| **2.Higher electrolyser costs & lower capture rates for blue hydrogen** | – The higher electrolyser costs lead to less electrolyser build-out, resulting in lower pipe utilisation in comparison to the base case. Although, this effect is minimal. |
| **3.Higher non-power $H_2$ demand – (greater regional spread)** | – The increase in demand does not significantly impact overall pipeline utilisation compared to the Base case. However, certain zone boundaries show higher utilisation, while others experience a decrease. |
| **4. Biomethane replacing hydrogen in power** | – *The biomethane sensitivity was modelled outside BID3 and without observing pipeline utilisation, so cannot be included within this analysis* |

AFRY

# Selected non-commercial benefits have been analysed to compare the impact of introducing the Backbone across the different sensitivities

(Backbone vs Counterfactual)

| NCB | | Sens 1 | Sens 2 | Sens 3 | Base case |
|---|---|---|---|---|---|
| **Emissions and societal $CO_2$ Cost Savings** | **Social cost of carbon savings (NPV £m, real 2023)** | 696 | 297 | 1,163 | 920 |
| **Integration of Renewable Electricity** | **Curtailment savings (TWh)** | 442 | 380 | 542 | 520 |
| **Integration of Green & Blue Hydrogen** | **Additional total $H_2$ production (TWh)** | 156 | 72 | 122 | 167 |
| | **Additional green $H_2$ production (TWh)** | 568 | 674 | 812 | 699 |
| **Power imports and gas reliance** | **Additional net power imports (TWh)** | 152 | 317 | 319 | 183 |
| | **Total gas use savings (TWh)** | 496 | 723 | 842 | 644 |

## Commentary

- Sens 3 delivers the strongest system benefits from the Backbone—highest $CO_2$ cost savings, largest curtailment reduction, and largest gas-use savings—but it also has the highest additional net power imports. All this is due to the extent of the electrolyser roll out.
- Sens 2 underperforms on $CO_2$ cost savings, but it provides good gas savings vs its CF. It appears the least efficient trade-off (e.g. lowest curtailment savings and $H_2$ production).
- The Base case is balanced: highest total $H_2$ volumes, strong curtailment reduction and $CO_2$ savings, and moderate import exposure.
- Sens 1 has the lowest import exposure but delivers the smallest gas and $CO_2$ savings owing to the limited reach of the Backbone.

All values are due to the implementation of the backbone in their respective sensitivity

↑ Better than the Base case
– The same or marginal difference than the Base case
↓ Worse than the Base case

# Higher $H_2$ demand in Sens. 3 delivers the greatest Backbone benefits, yielding ~£1.2bn in societal carbon cost savings vs ~£1.0bn (Base Case)

| | NCB | Base case | Sensitivity 1 | Sensitivity 2 | Sensitivity 3 | Overall summary |
|---|---|---|---|---|---|---|
| | | (Backbone vs Counterfactual)[1] | | | | |
| Environmental & Climate | **Societal CO₂ Cost Savings** | – ~£1bn in savings[2] | ↓ | ↓↓ | ↑ | **Savings**<br>Sens2. ~£0.3bn<br>Sens1. ~£0.7bn<br>Base ~£1bn<br>Sens3. ~£1.2bn |
| Environmental & Climate | **Risk of Water Stress[3]** | – May be a material impact in particular regions (S.Wales and N. Scotland), needs further analysis. | ↑ | ↓ | – | Sens.1 removes additional pressure on South Wales. Sens.2 concentrates nearly all additional water demand in Scotland—particularly in the North, which is itself currently a water-stressed region. |
| System Integration | **Integration of Renewable Electricity** | – Total of ~520 TWh of curtailment savings[2] | ↓ | ↓↓ | – | Sens.2 has the lowest curtailment savings of 380 TWh given that it has the lowest green hydrogen production. |
| System Integration | **Integration of Green & Blue Hydrogen** | 1. 167 TWh of more $H_2$ production[2]<br>2. 22% greater green hydrogen production | ↓ | ↓↓ | – | Sens. 3 matches the base case in added $H_2$ but delivers a lower share of green hydrogen. Sens. 2 shows both the lowest green-$H_2$ share and the smallest additional production vs its counterfactual. |
| Security of Supply | **Power imports and gas reliance** | 1. 183 TWh of more power imports[2]<br>2. ~ 644 TWh of gas use savings[2] | – | ↓ | – | Sens. 3 achieves the greatest gas-use savings from the backbone but also leads to the largest rise in net power imports. Sens. 2 exhibits a similar trade-off, with gas use savings closer to the Base case. |
| Security of Supply | **Gas Price Shock** | 1. £2.6 bn saving in shock year 2055 | – | ↓↓ | ↓ | Gas-price shock exposure tracks gas reliance: all cases depend more on gas, but Sens. 2 shows the highest absolute reliance under its BB case, making it the most sensitive to a gas-price shock. |

Note: 1 - All values refer to the Backbone as compared to the Counterfactual. 2 – over the modelled period of 2025-2060 (35 years) 3-does not include water needs for any other hydrogen production process such as SMR or Gasification

# Contents



Stakeholders engaged:



# Based on stakeholder input and internal analysis, four major risk categories have been identified as most relevant to the hydrogen backbone

**Public acceptability**

- The backbone could face local resistance, including potential public fears around safety and the local impact, which could challenge investment timelines.
- Low public acceptance can cause project delays, cost overruns, and route changes, creating slippages that cascade through the programme.

**Regulatory & policy uncertainty**

- Implementation delays, regulatory uncertainty, or shifts in government priorities
- Policy shifts reducing $H_2$ targets/mandates or incentives
- Projects may stall or lose value if the policy environment changes (e.g. full electrification preference)
- Inconsistent or shifting regulation and subsidy frameworks can undermine project bankability, distort investment timing, and discourage early movers.

**Demand uncertainty**

- Uncertain or slower-than-expected uptake of hydrogen in key sectors.
- Unclear or volatile hydrogen demand trajectories create the risk of over- or under-investment in network capacity. Overbuilding leads to stranded assets and underutilisation; underbuilding constrains industry uptake of $H_2$.

**Technological uncertainty**

- Risks related to the performance, maturity, and scalability of key hydrogen technologies, including electrolysers, CCS for blue hydrogen, hydrogen storage, and potential breakthroughs in competing energy vectors that could affect the backbone's role.

*Infrastructure risks such as coordination, development, and timing are second-order effects that stem from underlying uncertainties in demand, technology, policy, and public acceptance.*

Note: Stakeholder engagement sessions were held to attain feedback on sensitivities, non-commercial benefits and risks

# Risks are interconnected—uncertainty in one area can spill over into others, with policy & regulatory risk acting as a key amplifier or dampener

| "Source" (the influencing risk) | Risks | "Target" (the risk being influenced): Public acceptability | Demand uncertainty | Regulatory & policy uncertainty | Technological uncertainty |
|---|---|---|---|---|---|
| | **Public acceptability** | – | Public perceptions influence demand uptake (willingness to switch, support for hydrogen products and infrastructure rollout). | Public trust shapes regulatory stability and political backing. | Lower acceptance limits the volume of demonstrations, slows permitting and data collection, and reduces investment—adding uncertainty around when technology performance/costs shifts will occur. |
| | **Demand uncertainty** | Weak or uncertain demand reduces visible benefits (jobs, cost savings), undermining public support. | – | Hesitancy in demand signals by the private sector could make it harder for policymakers to set consistent rules and implement incentive schemes (for example to execute HAR financing). | Demand volatility limits R&D and deployment investment, curtailing investor appetite, and prolonging technological uncertainty. |
| | **Regulatory & policy uncertainty** | Weak or inconsistent regulation can erode public trust. | Policy instability weakens market signals and deters investment, increasing demand uncertainty. | – | Lack of policy direction reduces R&D support and slows technology development. |
| | **Technological uncertainty** | Safety and performance perceptions, especially of more immature technologies, affect public trust. | Technology immaturity or high costs make market adoption uncertain, leaving a gap between end-user willingness to pay and $H_2$ production costs. | Unclear technological pathways and costs make it harder for policymakers to design effective regulations and support schemes | – |

HAR = Hydrogen Allocation Round

# Risks and barriers could impact various modelling assumptions in AFRY's Base case, and are explored through sensitivity analysis

| | | AFRY modelling assumption inputs most affected | | | | | |
|---|---|---|---|---|---|---|---|
| | | Demand trajectory (timing & scale) | Capex / cost assumptions | Infrastructure rollout timing | Regional backbone siting / routing | Technology performance (efficiency) | Financing / WACC assumptions |
| | | Focus of: Sensitivity 3 | Focus of: Sensitivity 2 | Focus of: Sensitivity 1 | Focus of: Sensitivity 1 | Focus of: Sensitivity 2 | |
| Risks | 1. Public acceptability | | x | x | x | | x |
| | 2. Demand uncertainty | x | | x | x | | x |
| | 3. Regulatory & policy uncertainty | x | x | x | x | | x |
| | 4. Technological uncertainty | | x | x | | x | |

- Risks are not standalone; they materialise by challenging key assumptions (e.g. build times, costs, etc..).
- The table above highlights which assumptions are most affected by external risks beyond the boundaries of the model.
- The modelling outputs are based on a defined set of environmental and system assumptions, with select sensitivities used to explore the potential impacts of key uncertainties on outcomes.

# Any additional hydrogen demand has the highest impact on attained backbone induced total system cost savings compared to the base scenario

## MATERIALITY OF SENSITIVITIES ON BACKBONE INDUCED BENEFITS (TOTAL SYSTEM COST SAVINGS IN NPV TERMS)

| Sensitivity | Variable changed (i.e. assumption modified) | % change in variable compared to Base case | % change in benefit[4] (Sensitivity vs Base) | % change in benefit ÷[1] % change in variables | Materiality |
|---|---|---|---|---|---|
| 1 | Backbone size i.e. Toral backbone costs (CAPEX + OPEX) | ↓ -23% | 0% | 0% | Low |
| 2 | Electrolyser CAPEX[3]<br>Electrolyser OPEX[3]<br>Capture rates | ↑ +514%<br>↑ +30%<br>↓ -11% | -17% | -9%[2] | Medium |
| 3 | Non-power hydrogen demand increase | ↑ +50% | +67% | +133% | High |
| 4 | Biomethane instead of $H_2$ in power | | +17% | | Medium |

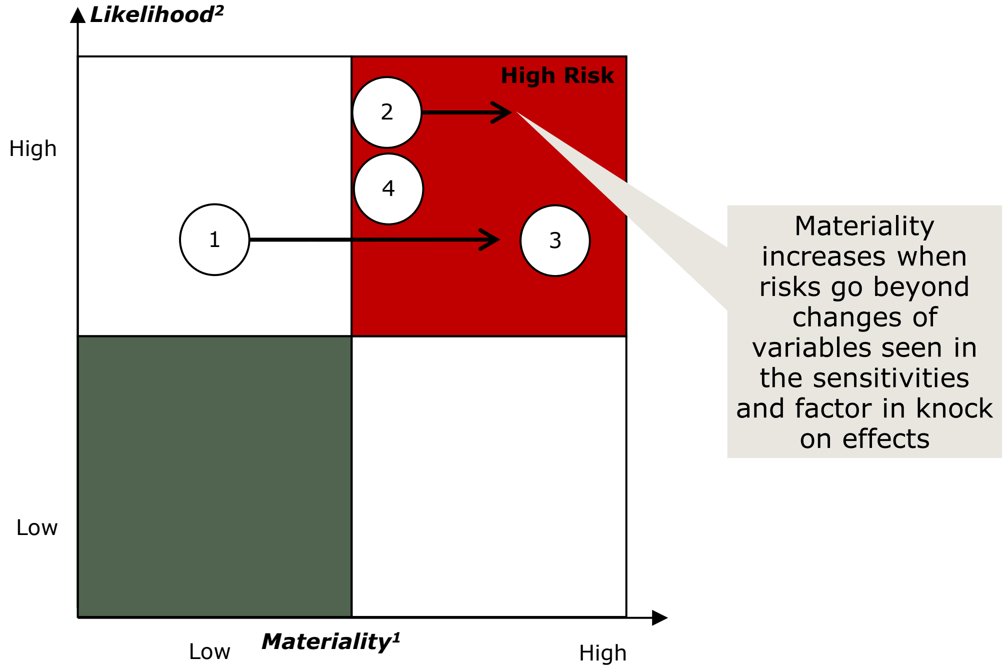
- This high-level analysis intends to provide a comparative sense of materiality across sensitivities, illustrating their relative influence on total system benefits.
- The intention is to map materiality from the sensitivities onto corresponding system wide risks.
- The sensitivity analysis serves as a quantitative proxy for four major categories of system risks identified earlier.
- The +133% in sensitivity 3 shows that the benefits compared to the Base case move +133% for every positive percentage change in demand. Although the regional demand spread dimension is not captured here but plays an important role, nonetheless.
- It is important to note this is a simplification providing an overall indication of assessing risks and materiality.

Note: **1)** column 4 divided by column 3. **2)** Average of the three variable changes used without weighting. **3)** Average across modelled years used. **4)** Represents % change (Sensitivity savings – Base Case savings/Base case savings)

Cautions of analysis: The analysis assumes linear relationships between input changes and total system costs; real-world effects may be non-linear. A given percentage change in an assumption (e.g., demand vs CAPEX) may not be equally meaningful across parameters

# Demand uncertainty is the most material risk to backbone benefits, amplified or dampened mainly by policy and regulatory (mis)alignments

## MATERIALITY VS LIKELIHOOD AND IMPACT OF WIDER RISKS




- **Materiality**: How much the assumption could impact the benefits of the BB case vs the CF?

Sens. 4 shifts backbone benefits by +17% relative to the base case, which is equal in absolute magnitude to the −17% outcome in Sens. 2, indicating a similarly material technology-driven effect—though the direction changes the risk interpretation (upside opportunity vs downside erosion).

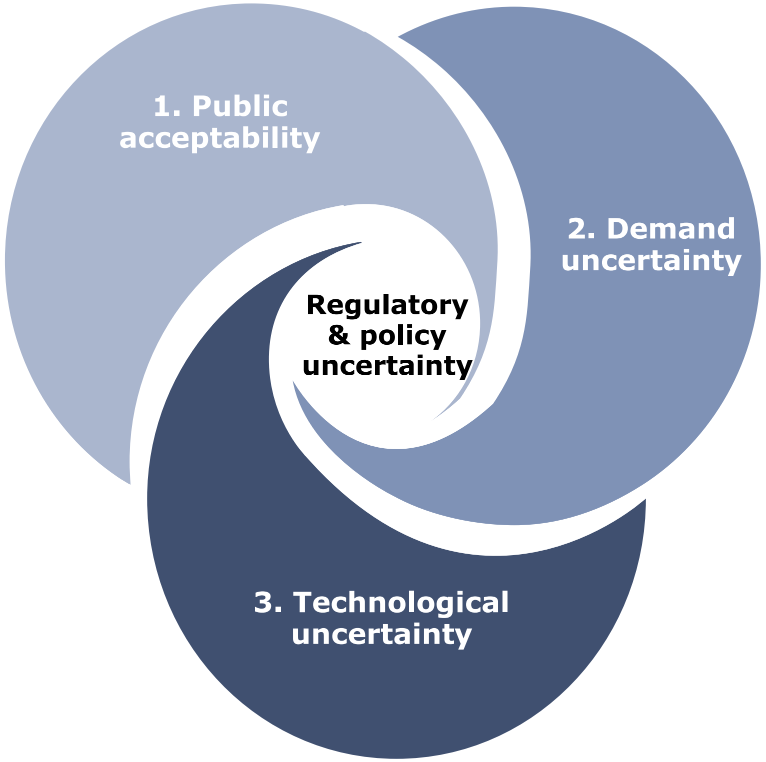
| Sensitivity | Key risk insights provided by the sensitivities |
|---|---|
| **1. Reduced and delayed hydrogen backbone** | • **Permitting delays due to public opposition** are likely to have low materiality <u>as long as</u> the main BB connects major clusters in a timely fashion (e.g. Scotland to Humberside and Merseyside)<br>• If the main BB is further delayed or fragmented due to parts being blocked or held up; total system cost savings decline, with knock-on effects across other risk areas. |
| **2. Reduced blue $H_2$ capture rates & higher electrolyser costs** | • **Technological uncertainty** Technological under-performance in electrolysis and blue $H_2$ does not flip the backbone case, but it meaningfully erodes its value.<br>• If another energy vector dominates, the benefits of the backbone face higher risk as further demonstrated by sensitivity 4. |
| **3.Higher non-power hydrogen demand** | • Demand fluctuations are both highly material and highly uncertain.<br>• This means the backbone's benefits are most vulnerable when demand fails to align with the backbone's rollout in a timely fashion. |
| **4. Biomethane replacing hydrogen in power** | • **Policy and regulatory risks** amplifies all other risks as it undermines strategic alignment and a system wide coordinated effort.<br>• A double vector policy approach for example, if not deliberate, as shown in the sensitivity will erode benefits further.<br>• ***However, if rolled out in a coordinated fashion will continue to provide marginal benefits through the BB.*** |

Note: CF – Counterfactual scenario, BB – Backbone scenario
1) No Weighting applied to materiality 2) Likelihood assessments are qualitative and judgement-based, informed by literature.

# Building on the UK's hydrogen and CCS policies, clearer, more stable, and better-coordinated regulation is needed to reduce risks

## Mitigation of Risks




### 01 | Public acceptability

**Goal:** Build legitimacy and social license early to avoid late-stage project resistance.

– Engagement & governance — proactive communication, transparent safety standards, local benefit integration
– Use of existing infrastructure to reduce footprint

### 02 | Demand uncertainty

**Goal**: Reduce risk of stranded assets and ensure infrastructure grows in step with long-term demand

– Phased modular design – Stage investments to allow scaling up or rerouting as demand evolves.
– Align backbone rollout with industrial clusters and their uptake of demand
– Ensure the HPBM fully accounts for the difference between market price and all costs, and allow for realistic schedules for demand offtake

### 03 | Technological uncertainty

**Goal:** Accelerate learning, ensure system compatibility, and lower commercial risk

– Targeted R&D and funding – Prioritise tech that addresses integration challenges (e.g. $H_2$ storage + pipeline interoperability, CCS technology, electrolyser learning rates) and support regional hydrogen and CCS test hubs .

## Regulation & Policy

The UK already has a relatively advanced policy framework for hydrogen and CCUS development — including the Hydrogen Production Business Model (HPBM) with its Hydrogen Allocation Rounds, the CCUS Cluster Sequencing Process, the Net Zero Hydrogen Fund (NZHF). However, there are still delivery gaps and uncertainties that need to be addressed in the upcoming refresh of the National Hydrogen Strategy

**Build on what exists:**

– Enhance alignment across wider GB energy system, including hydrogen policy, targets, investments and allocation rounds, CCUS clusters, gas/biomethane policy, networks and incentives, and backbone development to ensure infrastructure and demand evolve together.
– Provide more policy visibility with multi-year allocation plans and clear regulatory milestones to give investors confidence beyond the first wave of projects.

**Address remaining gaps:**

– Strengthen cross-sector coordination between production, storage, and end-use planning to prevent bottlenecks and stranded assets.
– Streamline permitting and public engagement for $CO_2$ and hydrogen infrastructure to build confidence and accelerate delivery.
– More focus on enabling hydrogen demand with clarity on priority sectors, rather than top-down supply targets

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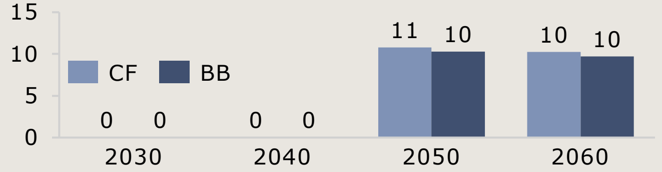
# Two additional sensitivities were conducted to assess the viability of an $H_2$ backbone when biomethane supplies power or non-power industrial demand

## SENSITIVITIES

**5**

| Electrolyser costs | | |
|---|---|---|
| **Avg. 2025-2060** | **Base case** | **Sensitivity** |
| **Capex £/kw** | 248 | 1520 |
| **Opex £/kw/yr** | 42 | 55 |

**UK biomethane fuel use in power as provided by the model (TWh)**

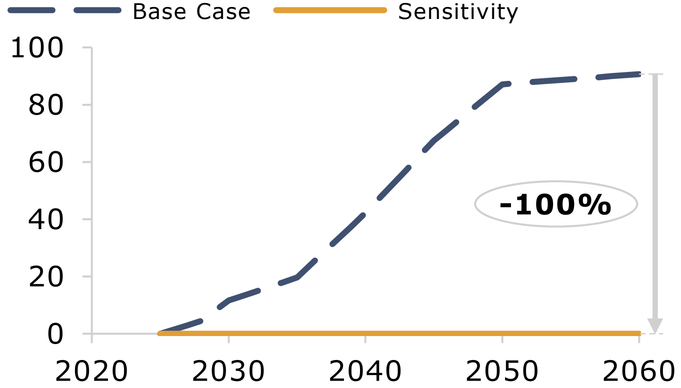



### 5. Reduced blue $H_2$ production capture rates & higher electrolyser costs and biomethane introduced in power as an available fuel

- Reduced carbon capture rates for blue hydrogen production **95% to 85%**
- Increased electrolyser costs to match NESO's 'Levelised Cost of Green Hydrogen' dataset (October 2023)
- Iteration of the backbone to optimise the pipeline capacities based on flows.
- Biomethane is part of the model optimisation. The model is allowed to select biomethane thermal units for build along with CCGT $H_2$ thermal units, both with similar technology costs and technical characteristics including being carbon neutral.
- The biomethane fuel price used–by the biomethane thermal units is the volume-weighted average feedstock price using AFRY's Central feedstock price assumptions and the projected availability of each feedstock type (see Annex.)

**6**

**UK biomethane replacing $H_2$ in non-power (TWh)**




### 6. Replacing $H_2$ non-power demand with biomethane

- Biomethane replaces all hydrogen as a fuel in the non-power sector for both Counterfactual (no backbone) and the Backbone case.
- In contrast to Sensitivity 5, biomethane demand profile is an exogenous input and not part of the model optimisation. The cost in satisfying the demand is exogenously calculated.
- Biomethane as fuel in non-power reaches **~90 TWh** by 2060 in the Backbone case and the Counterfactual.
- Iteration of the backbone to optimise the pipeline capacities based on flows.

Tipping points: Changes in drivers/assumptions that result in the needs case for a national hydrogen backbone materially changing. can impact the commercial needs case positively or negatively.

**Modelled in Bid3**
**Backbone iterated**

# Contents



# The Base case and Sensitivities 5 and 6 were iteratively refined based on individual pipe performance against three key criteria

## 1 PIPE TIME SPENT AT PEAK UTILISATION

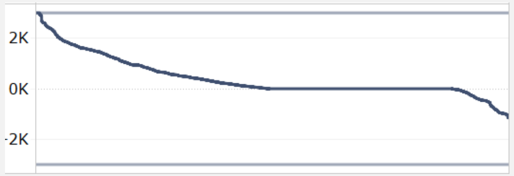
An example of a hydrogen pipeline (Upper NE to NE in 2035), where it was constrained, and therefore its capacity was increased

Original – 1 GW


Current – 3.8 GW


An example of a pipeline (NE to Midlands in 2045), where it was underutilised, and therefore its capacity was decreased

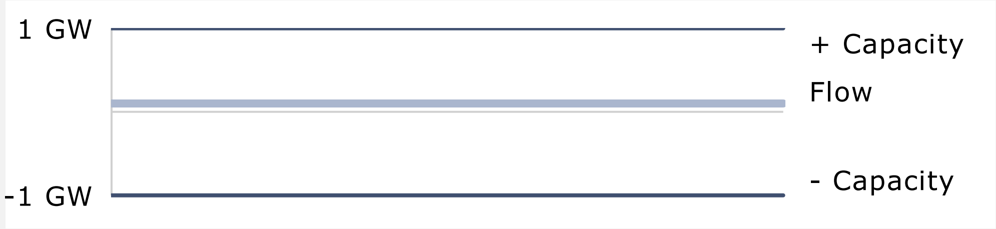
Original – 3 GW



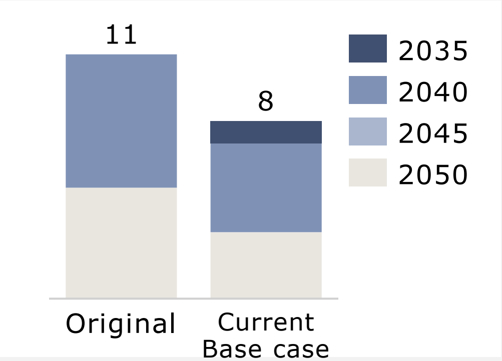

Current – 2 GW


## 2 LOWEST FEASIBLE PIPELINE CAPACITY

An example of a pipeline (Midlands to London in 2040), where the flow rate is insufficient to warrant developing the pipeline until a later year




## 3 NUMBER OF STEPS FOR PIPELINE CAPACITY ENHANCEMENT




It has been assumed that the backbone would be future-proof. Therefore, the aim was to limit the number of steps for capacity increase, where reasonable, in order to avoid multiple pipes being built along the same route in a short period of time.



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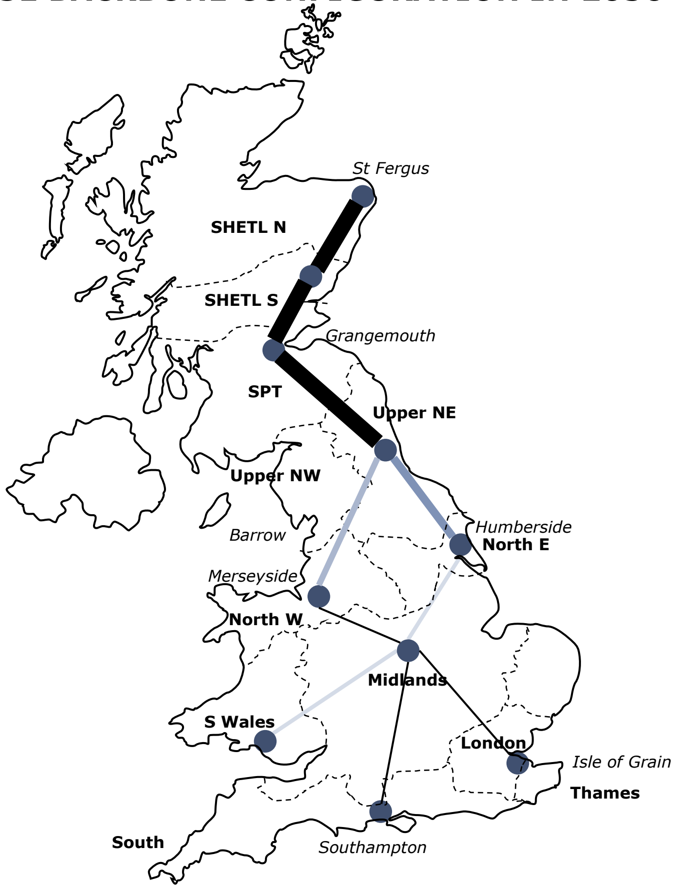
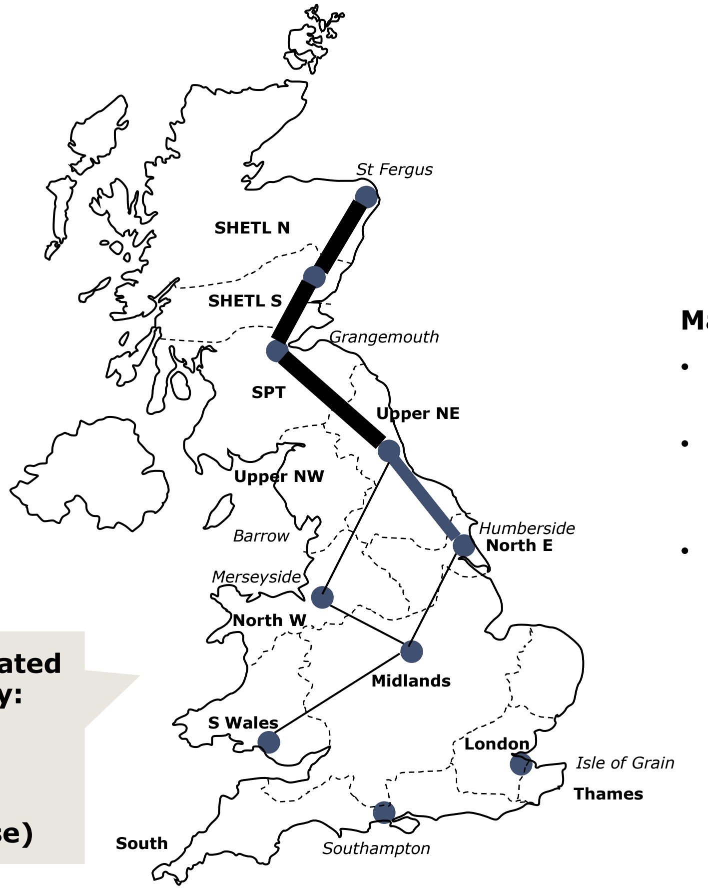
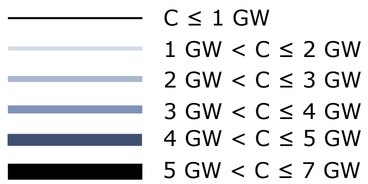
# In Sensitivity 5, $H_2$ pipeline build is lower in total capacity in 2050 especially around the Midlands zone due to lower $H_2$ to power demand

**BASE CASE BACKBONE CONFIGURATION IN 2050**




**SENSITIVITY 5 BACKBONE CONFIGURATION IN 2050**




**Total 2050 aggregated pipeline capacity:**

**26.5 GW**

**vs**

**32 GW (Base case)**

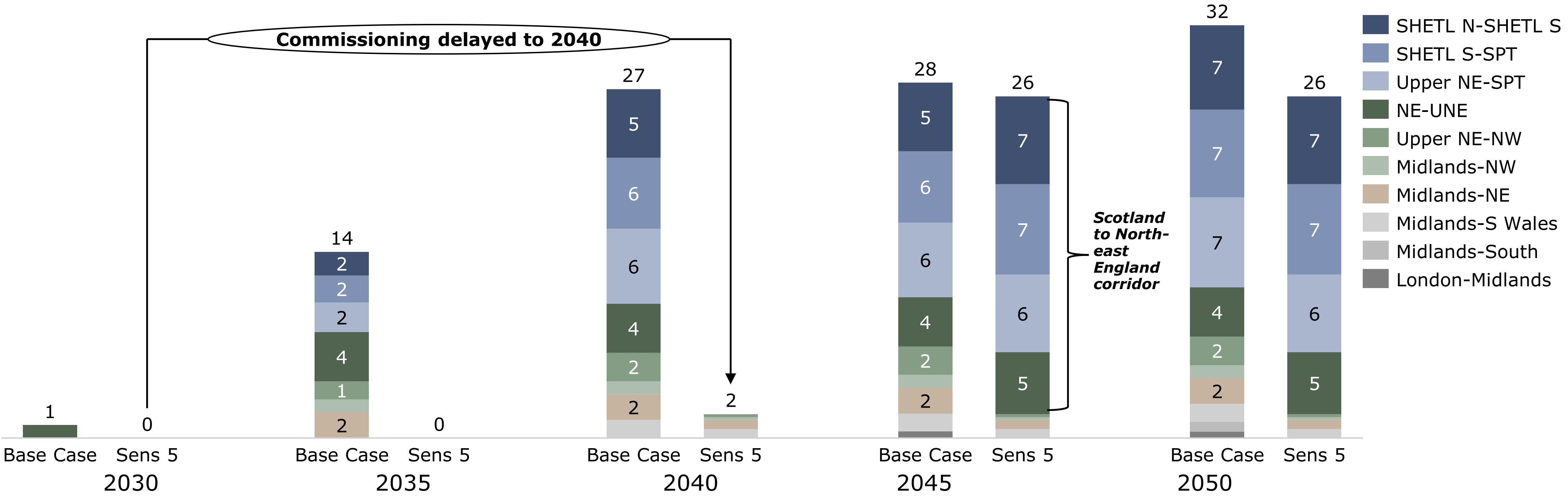
**Main adjustments:**

- Removed pipelines from Midlands to the south of GB
- Reductions in pipeline capacity from Midlands to South Wales.
- Reduction in pipeline capacity from Northwest to Upper Northeast zones

# In Sensitivity 5, initial hydrogen pipeline commissioning shifts from 2030 to 2040, with greater eventual build-out in Scotland and Northern England

## PIPELINE CAPACITY COMMISSIONED BY MILESTONE YEAR, BASE CASE AND SENSITIVITY 5 (GW)

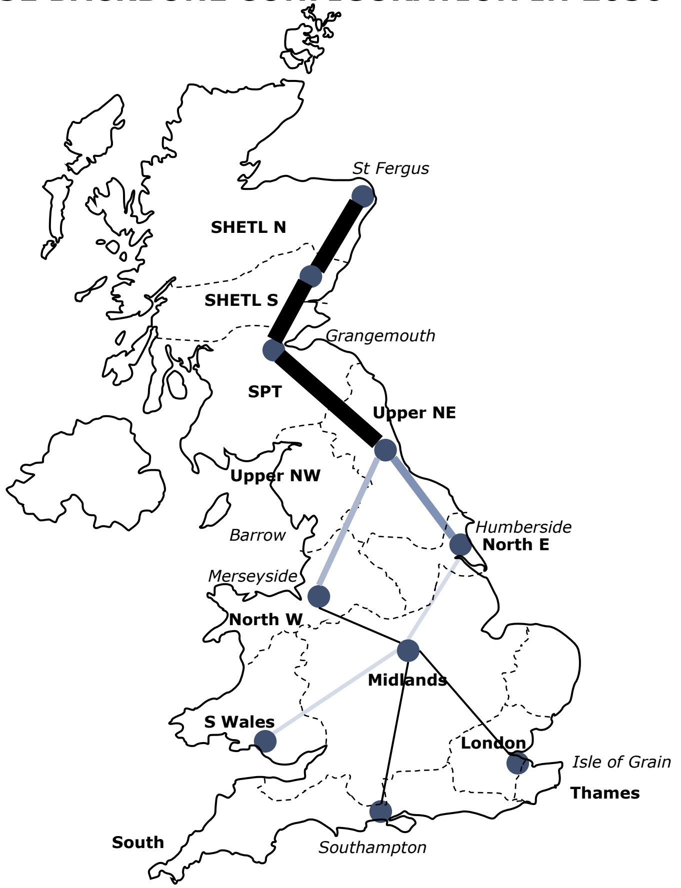



- Under Sensitivity 5 (Sens 5) the first meaningful commissioning of the pipeline occurs only from 2040, reflecting slower hydrogen demand growth and reduced competitiveness of hydrogen production, as well as a hydrogen production system dominated by SMR-CCS, where electrolysers are only built from 2040 onwards.
- Post 2040 the strongest volumes appear in Scotland and the North England as compared to the Base case, where $H_2$ supply remains most competitive. This reflects the stronger economics of low-carbon hydrogen production in these regions, despite overall higher costs.

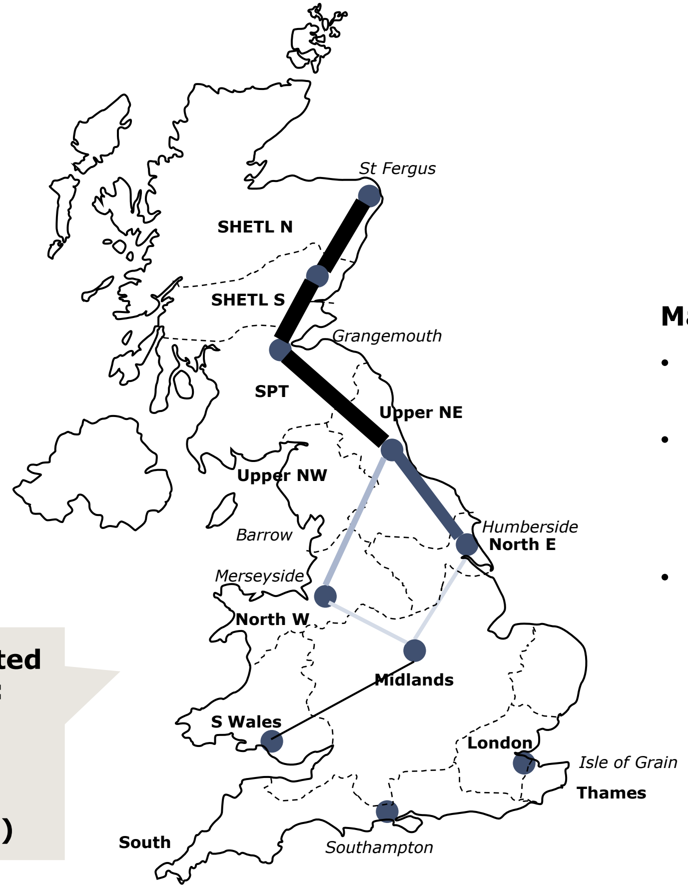
All capacities are rounded

# In Sensitivity 6, total $H_2$ pipeline capacities in 2050 are reduced compared to the Base case as biomethane replaces all non-power industrial $H_2$ demand

**BASE CASE BACKBONE CONFIGURATION IN 2050**




**SENSITIVITY 6 BACKBONE CONFIGURATION IN 2050**




C ≤ 1 GW
1 GW < C ≤ 2 GW
2 GW < C ≤ 3 GW
3 GW < C ≤ 4 GW
4 GW < C ≤ 5 GW
5 GW < C ≤ 7 GW

**Total 2050 aggregated pipeline capacity:**

**29 GW**

**vs**

**32 GW (Base case)**

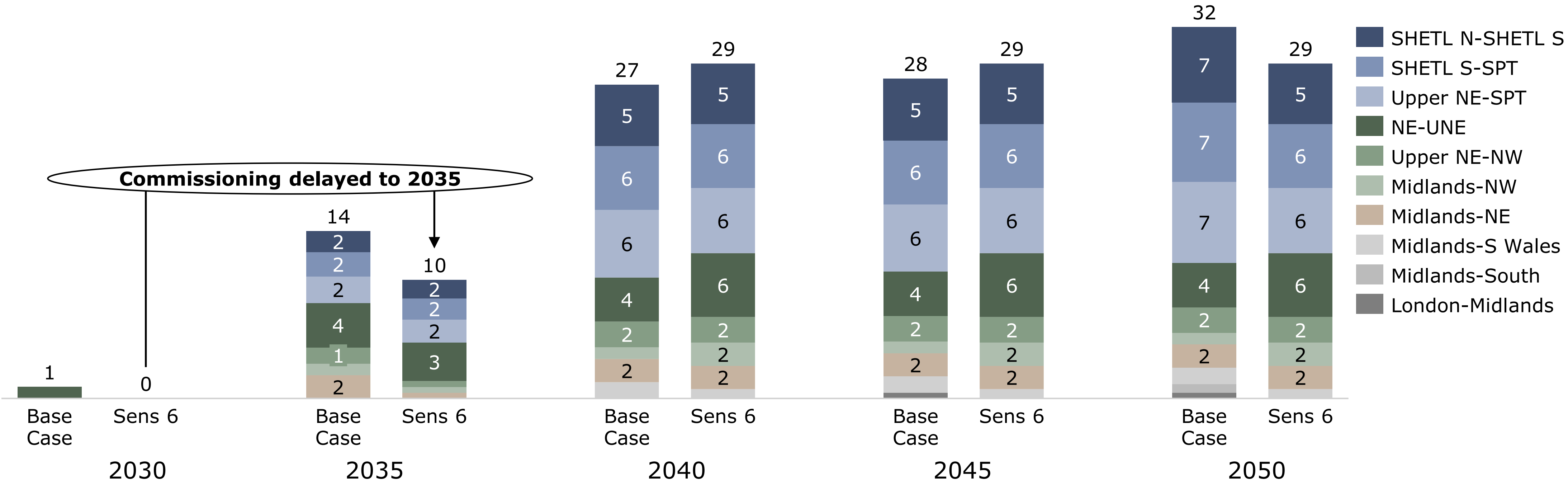
**Main adjustments:**

- Removed pipelines from Midlands to the south of GB
- Reductions in pipeline capacity from Midlands to South Wales and the Northern zones.
- Slight increase in pipeline capacity from Midlands to Northwest.

# $H_2$ pipeline commissioning is delayed from an initial milestone year of 2030 to 2035, with greater build out in North England and less build in Scotland

**PIPELINE CAPACITY COMMISSIONED BY MILESTONE YEAR, BASE CASE AND SENSITIVITY 5 (GW)**

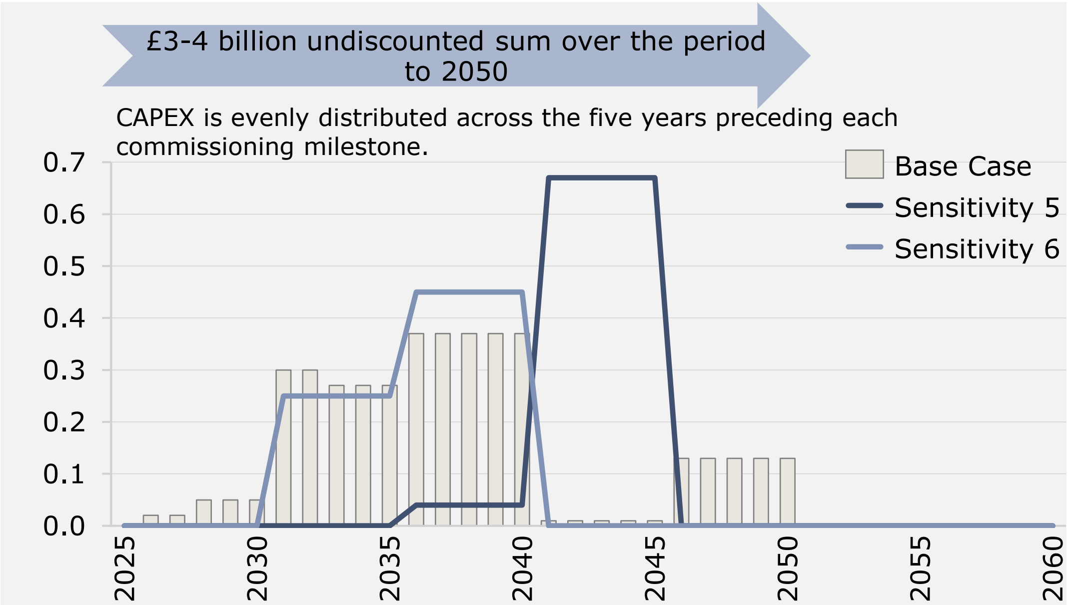



- The first meaningful commissioning occurs only from 2035, reflecting the absence of non-power industrial hydrogen demand as it is all supplied by biomethane.
- The backbone is built to its highest capacity in 2040, even surpassing that of the Base case, to support the predominantly green hydrogen production system to meet the $H_2$ to power demand. Much of the build is concentrated in Scotland and North-east England due to excess RES that leads to relatively cheaper $H_2$.
- By 2050, the pipeline capacity of the sensitivity becomes less than that of the Base case due to the absence of the non-power industrial hydrogen demand

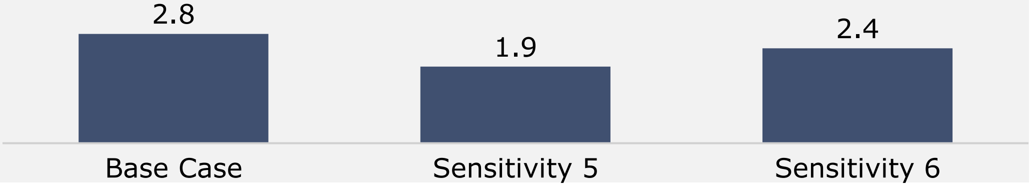
 

# There is significantly different backbone infrastructure build profiles between the three cases where the backbone is iterated

## ANNUAL HYDROGEN PIPELINE + COMPRESSOR CAPEX PHASING - SPREAD BY BUILD TIME (£ BN, REAL 2023)




NPV* OF PIPELINE + COMPRESSORS **CAPEX ONLY** (£BN, REAL 2023)




* NPV is on a 35-year (2025-2060) period using a rate of 3.5% for the first 30 years and 3% for the last 5 years

## COMMENTARY

- The summed undiscounted cost of the pipeline network (including compressor costs) which is based on the NTS level only comes to just over **£4 bn (£2.8 bn in NPV terms)–** this represents just over **1,700 km** of transmission infrastructure totalling **32 GW** by 2050 for the Base case.
- In Sensitivity 5, the pipeline build-out only begins post-2035, with most of the backbone being built by 2045. The summed undiscounted cost of the pipeline network + compressors comes to ~**£3.6 bn (£1.9 bn in NPV terms)** – this represents just over **1,285 km** of transmission infrastructure totalling **26 GW** by 2050.
- In Sensitivity 6, the pipeline build-out takes place in the 2030s. The summed undiscounted cost of the pipeline network comes **£3.5 bn (£2.4 bn in NPV terms)** – this represents just over **1,285 km** of transmission infrastructure totalling **29 GW** by 2050.
- For a similar route length to Sensitivity 6 (~1,285 km), delaying construction in Sensitivity 5 reduces the NPV by around £0.5 bn (≈26%), despite only a ~£0.1 bn difference in undiscounted costs. NPV analysis alone may incentivise delay, but the broader energy-system logic may favour earlier, more comprehensive build-out to enable hydrogen scale-up and meet broader strategic targets.

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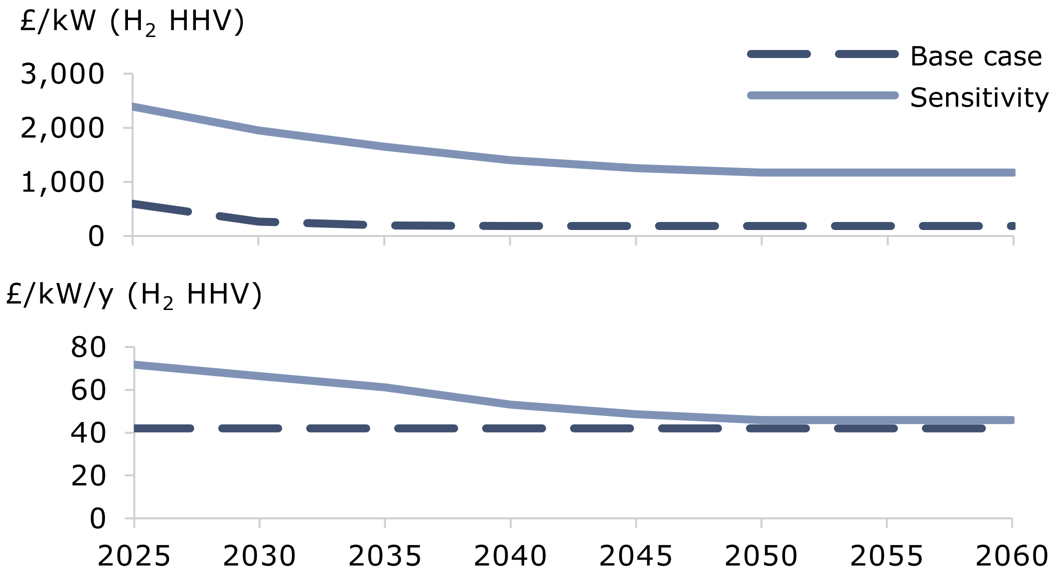
EXTRA SENSITIVITIES | SENSITIVITY 5 - BIOMETHANE IN POWER SECTOR

# This sensitivity includes biomethane-fired power generation and assumes higher electrolyser costs and lower SMR-CCS capture rates

## CCS CAPTURE RATE FOR BLUE H2 PRODUCTION

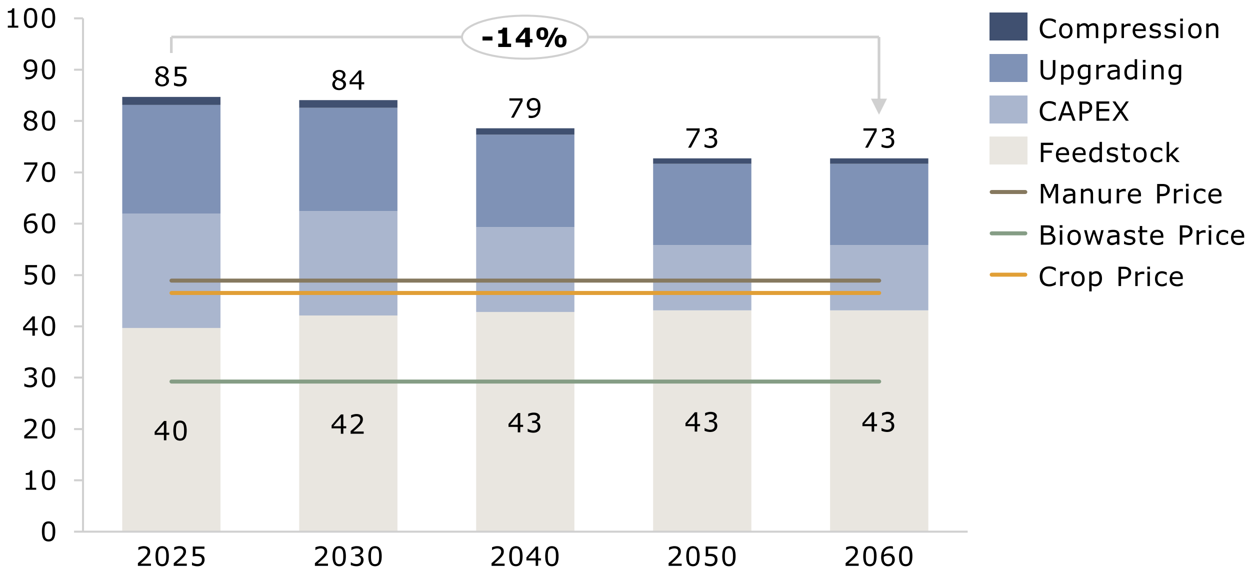
| | Base case | Sensitivity |
|---|---|---|
| **Blue $H_2$ production carbon capture rate** | 95% across all future years | 85% across all future years |

## ELECTROLYSER COSTS*




*Source of electrolyser costs for sensitivity: https://www.neso.energy/data-portal/levelised-cost-green-hydrogen

## BIOMETHANE COST ASSUMPTIONS (£/MWH REAL 2023)




In this sensitivity, the volume-weighted average feedstock price (between manure, biowaste and crop) was derived for the projected years; using AFRY's Central feedstock price assumptions and the projected availability of each feedstock type.

# This sensitivity is characterised by CCGT-biomethane replacing CCGT-$H_2$ and higher SMR-CCS $H_2$ supply, resulting in reduced $H_2$ storage and RES build-out

**KEY STORYLINES**

| | |
|---|---|
| **1** | **Dispatchable generation:** Compared to the Base case, the sensitivity is characterised by more CCGT biomethane build replacing CCGT H2 as the main dispatchable generation technology due to the higher costs of hydrogen production. The Backbone allows slightly more economic build of CCGT $H_2$ capacity reflecting better access to lower cost hydrogen which replaces a small amount of CCGT biomethane. |
| **2** | **$H_2$ production:** Higher electrolyser costs lead to far less electrolyser build in the sensitivity compared to the Base case, making SMR-CCS the primary $H_2$ source. The Backbone supports more Scottish electrolyser capacity, replacing some SMR-CCS and producing a more balanced system. |
| **3** | **Hydrogen storage:** Hydrogen storage falls sharply in the sensitivity compared to the Base case due to lower electrolyser build and reduced $H_2$-to-power demand. With a Backbone, more storage—mainly salt caverns in the North—is added, as these sites can access cheaper hydrogen from additional Scottish electrolysers. |
| **4** | **Electricity transmission network:** Transmission build in the sensitivity is lower than in the Base case because CCGT-biomethane is built in demand centres, reducing the need for north–south reinforcement. Adding the Backbone further reduces transmission requirements, but to a smaller extent than in the Base case. |
| **5** | **Renewables:** Onshore wind and solar PV capacity fall in the sensitivity due to limited electrolyser build and lower $H_2$-to-power demand compared to the Base case. The Backbone boosts renewables—particularly solar PV—because it enables a larger relative increase in electrolysers compared with the Counterfactual |
| **6** | **Electricity Storage:** 6-hour batteries fall in the sensitivity as biomethane CCGTs meet demand locally, reducing flexibility needs. LDES increases—mainly in the North—to store excess wind due to limited electrolyser deployment. The Backbone makes only small differences relative to the Counterfactual. |

Refer to the Annex for more details

# Even with higher electrolyser costs, lower blue $H_2$ capture rates and competition from biomethane the Backbone still provides marginal benefits

## KEY MESSAGES

**1**

**Compared to the Base case:**

Sensitivity 5 shows total system costs £9–10 bn higher than the Base case in both CF and BB scenarios over the modelled period. This is mainly due to greater deployment of SMR-CCS, which becomes the preferred option as electrolyser costs rise. The larger SMR CCS build-out increases variable OPEX and adds costs due to its lower $CO_2$ capture rate. The sensitivity also includes extra CCGT-biomethane investment not seen in the Base case. These additional costs outweigh savings from reduced CCGT-$H_2$, RES, electrolyser, and $H_2$-storage deployment.

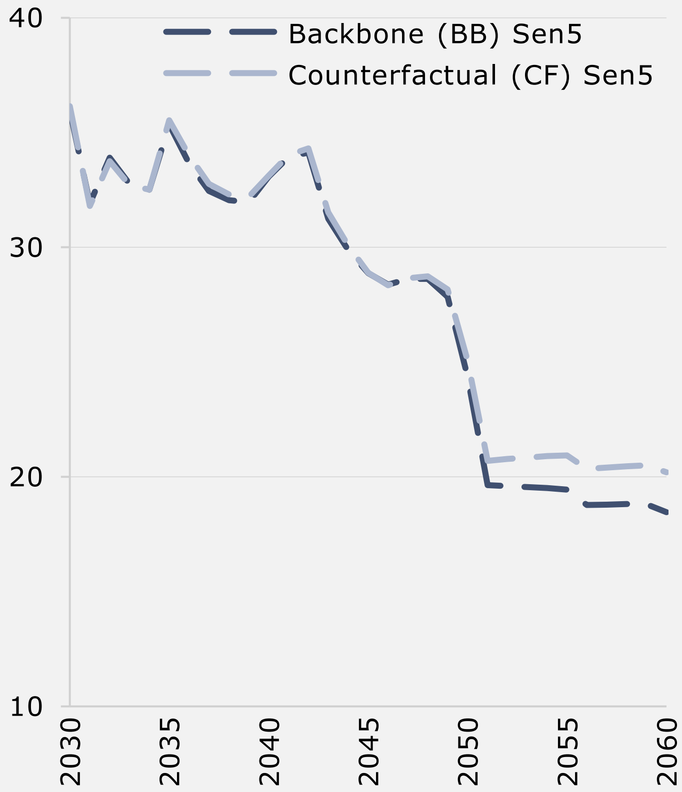
**2**

**Sensitivity 5 BB-CF:**

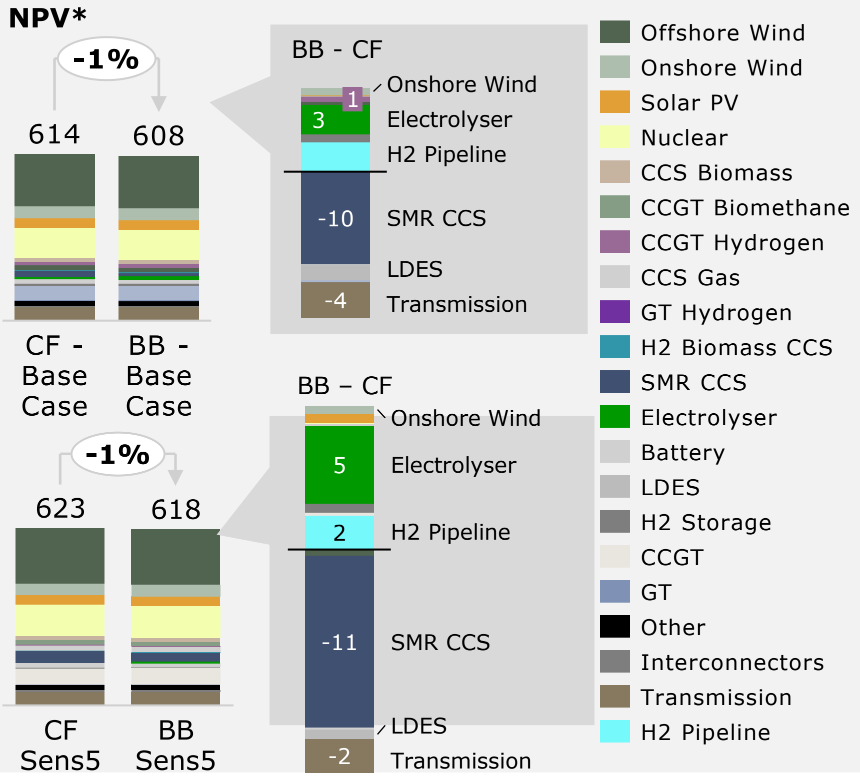
Within the sensitivity the backbone cuts system costs by ~£5 bn over the modelled period by enabling electrolyser deployment in Scotland, which reduces SMR-CCS cost contributions and lowers CCGT-biomethane, LDES, and transmission costs. These savings outweigh the extra costs of electrolysers, pipeline, and RES build in the BB scenario.

## SENSITIVITY 5 SYSTEM COST COMPARISON - CF VS BB WITHIN SENSITIVITY

ANNUAL SYSTEM COST (BN £, REAL 2023)




TOTAL SYSTEM COST BY TECH – BB & CF COMPARISON (BN £, REAL 2023)




Notes: CF – Counterfactual scenario, BB – Backbone scenario. Where there is no "Sen" mentioned with CF or BB then this refers to the Base case.
* NPV is on a 35-year (2025-2060) period using a rate of 3.5% for the first 30 years and 3% for the last 5 years



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# Sens 5 has higher costs than the Base case due to high SMR-CCS costs which more than offsets savings from building less electrolysers, RES, and $H_2$ storage

## KEY MESSAGES

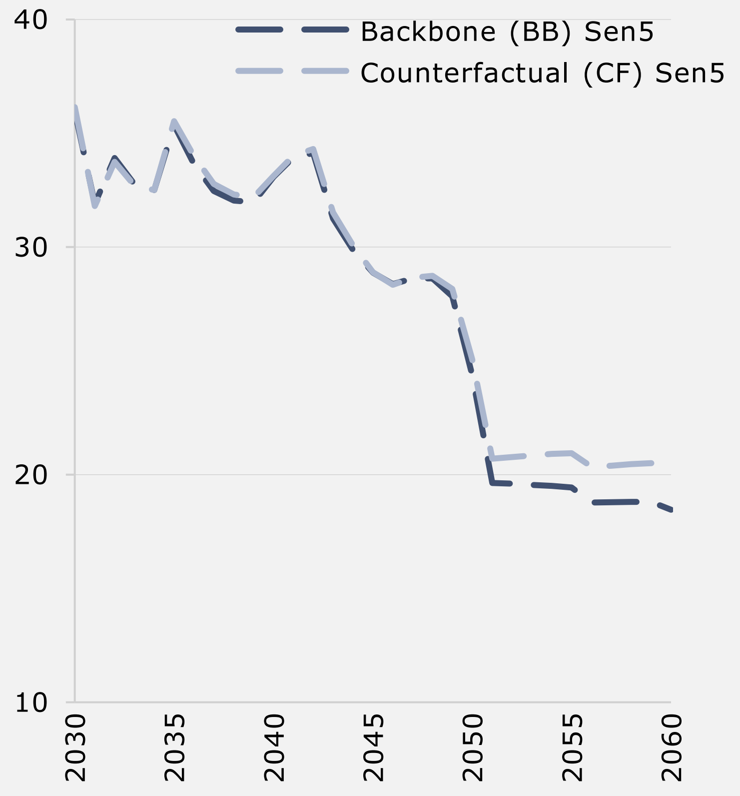
1 By allowing biomethane CCGTs to be considered by the model to build as an option along with CCGT $H_2$ thermal units, the model has built significant capacity of biomethane plants located in demand centres in both the CF and the BB case.

2 In Sensitivity 5, both the Counterfactual and Backbone scenarios are around £9–10 bn more expensive than the Base case. This is primarily driven by a larger build-out of SMR-CCS, which becomes the preferred supply option when electrolyser costs are high.

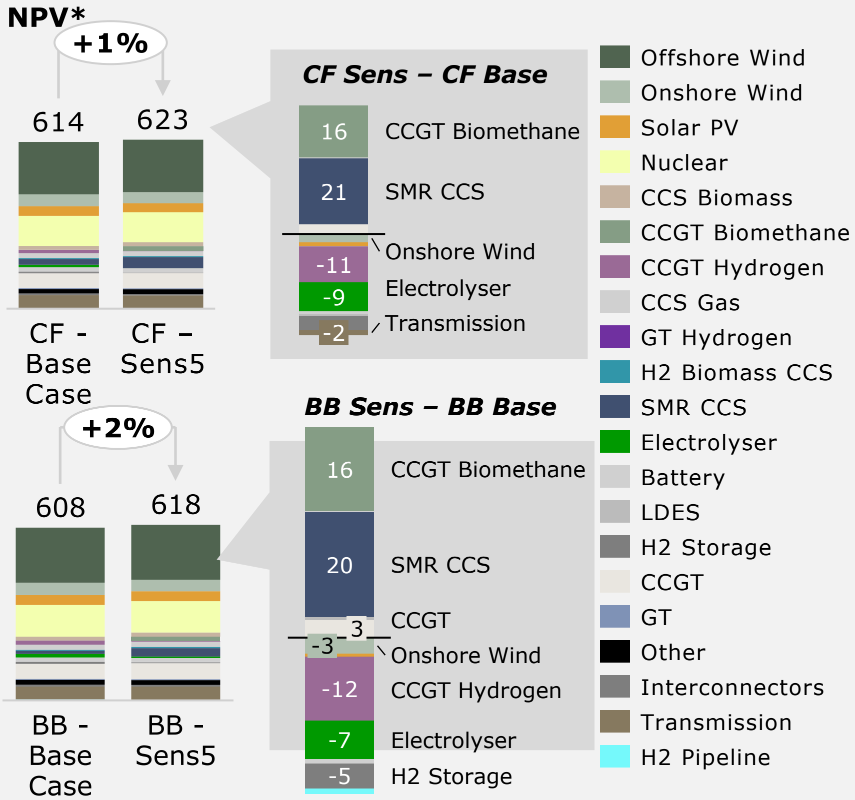
3 The greater SMR-CCS deployment increases total variable OPEX, and the lower capture rate further amplifies these costs. Additional expenditure on CCGT-biomethane capacity adds to the overall system cost. Together, these factors more than offset the savings from building less CCGT-H₂, RES, electrolysers, and $H_2$ storage compared with the Base case.

## COMPARISON OF CF AND BB SYSTEM COSTS TO THE BASE CASE

ANNUAL SYSTEM COST (BN £, REAL 2023)




TOTAL SYSTEM COST BY TECH – SENSITIVITY & BASE CASE COMPARISON (BN £, REAL 2023)

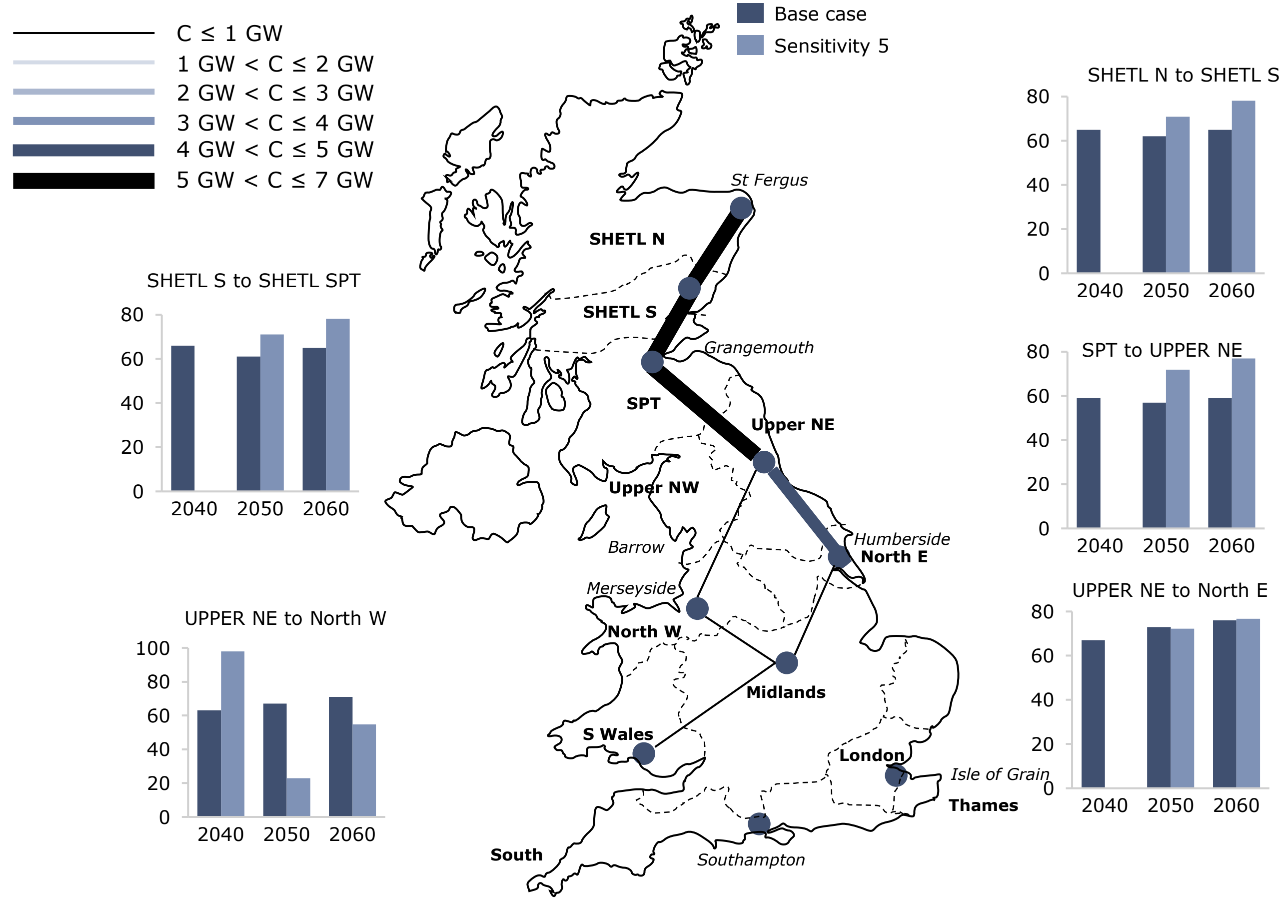



Notes: CF – Counterfactual scenario, BB – Backbone scenario. Where there is no "Sen" mentioned with CF or BB then this refers to the Base case.
* NPV is on a 35-year (2025-2060) period using a rate of 3.5% for the first 30 years and 3% for the last 5 years

# Scottish pipes are utilised more by 2050 compared to the Base case due to a higher concentration of electrolyser build in Scotland versus other zones

## HYDROGEN PIPES UTILISATION (%)




Note: Pipeline capacity in map is shown for the year 2050.

## COMMENTARY

- In this sensitivity much of the pipeline commissioning (especially those pipelines in Scotland) are delayed to after 2040 due to slower hydrogen demand growth, thus there is no utilisation of the pipeline in 2040.
- However, in 2040, there is more utilisation in the Upper Northeast to Northwest pipeline in the sensitivity compared to the Base case as it is being relied on more to supply blue hydrogen to $H_2$-CCGT's in the North W until Scottish pipelines are built.
- In 2050 and 2060, the Scottish pipelines are utilised more compared to the Base case as electrolyser build is more concentrated in Scotland. As a result, the pipelines connecting Scottish zones to each other and to north of England are being relied on more to transport hydrogen.
- On the other hand, the Upper Northeast to Northwest pipeline is utilised less in 2050 and 2060 due to the absence of build of salt caverns in the Northwest zone.

# Cost savings due to the introduction of a backbone exist under Sensitivity 5 but are less than the Base case

**Sensitivity insights**

– Cost savings due to the introduction of a backbone exist under Sensitivity 5 but are marginally less than the Base case.
– Even under higher estimates of electrolyser costs, higher SMR-CCS OPEX, and the option of building biomethane thermal plants, the backbone continues to deliver savings with the Scotland-Northeast England being the most heavily utilised part.
– The primary driver of cost savings remain the reduction of SMR-CCS after introducing the backbone.
– As long as there is a substantial, stable non-power (industrial) baseload hydrogen demand, the backbone remains beneficial.
– Connecting Scottish electrolysers with storage and demand centres reduces reliance on SMR-CCS and continues to generate system-level savings.

**Limits of the sensitivity**

– The sensitivity draws some light on the potential impacts of technology cost and performance uncertainty.
  – The conclusion that the backbone remains beneficial partly relies on the presence of a strong, stable industrial baseload for $H_2$. If this demand is smaller, delayed, or more flexible, the system value of the backbone may change significantly.
  – The model allows CCGT-biomethane build in demand centres. In practice, feedstock limitations, sustainability criteria, or geographic constraints may restrict deployment.
  – Gas-network costs are not included for biomethane flows.
  – The model does not allow for network limitations from biomethane, such as upgrading infrastructure needs.

**Wider risks beyond the sensitivity***

– Biomethane power demand of 10-11 TWh by 2050 in this sensitivity is way below estimated feedstock availability of 120 TWh.* In reality, feedstock constraints, regulatory changes, sustainability requirements, land-use constraints, and competing uses (heat, transport, industry) could limit feedstock availability and raise system costs.
– As fossil gas usage declines, the costs of operating, maintaining, and eventually decommissioning the gas network must still be recovered from a shrinking user base. This creates long-term regulatory and affordability challenges that intersect with any shift toward biomethane or hydrogen.

* Refer to sensitivity 2 for further discussions on wider risks * Estimate from Green Gas Taskforce see Annex 1 for more details.

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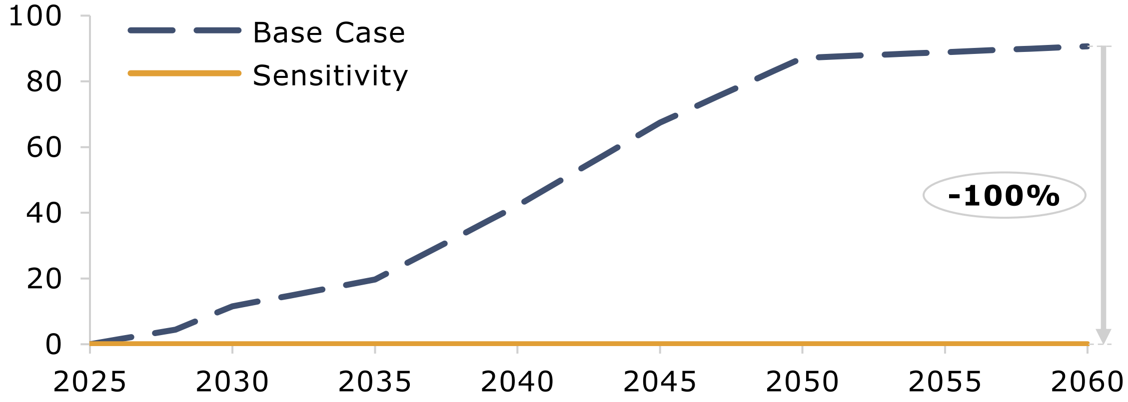
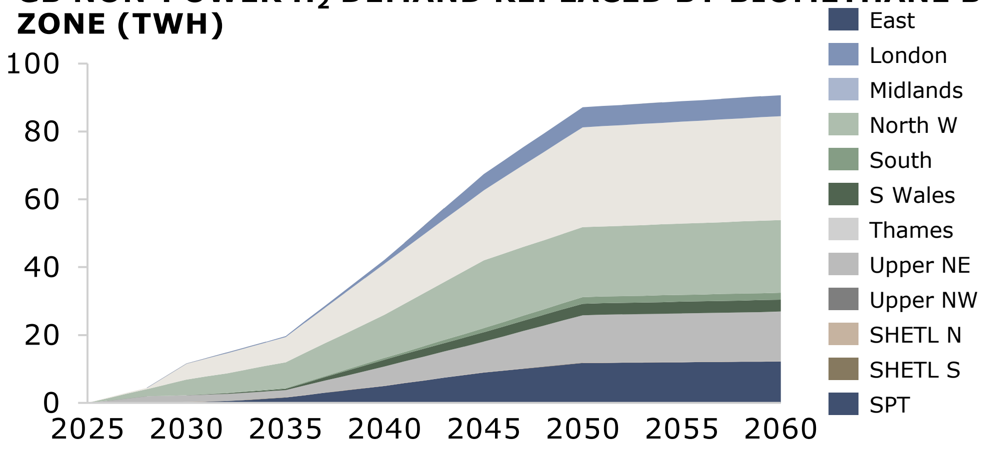
EXTRA SENSITIVITIES | SENSITIVITY 6 - BIOMETHANE COVERING NON-POWER $H_2$ DEMAND

# It has been assumed that all non-power industrial hydrogen demand is met by biomethane, which may not be feasible based on UK feedstock availability

## GB NON-POWER $H_2$ DEMAND REPLACED BY BIOMETHANE (TWH)




## GB NON-POWER $H_2$ DEMAND REPLACED BY BIOMETHANE BY ZONE (TWH)




**COMMENTS**

- By 2060, the Base case has around 91 TWh of non-power industrial hydrogen demand where the majority is in the North of GB corresponding to the main hydrogen industrial clusters.
- In this sensitivity, it is assumed that the supply of biomethane is sufficient to meet the entire industrial demand that was originally assumed to be fulfilled by hydrogen in the Base case scenario. This means that instead of relying on hydrogen for industrial applications, biomethane is assumed capable of fully substituting hydrogen's role in satisfying industrial demand.
- The model adopts a simplified view of how non-power sectors decarbonise with biomethane, without representing potential biomethane supply constraints, competing uses, and the fact that biomethane is not a straight replacement for hydrogen in all applications.
- The 91 TWh biomethane demand by 2050 sits below the Green Gas Taskforce's theoretical 120 TWh limit but may exceed realistic availability (see Annex). NESO included up to 64 TWh of biomethane by 2050 in Future Energy Scenarios (2025), which 91 TWh exceeds. Rising demand from other end-uses not included in our original non-power $H_2$ estimate—most notably residential heat—could further constrain feedstock, leaving insufficient biomethane to meet the 91 TWh requirement.
- The price of biomethane fuel is the same as what was used in sensitivity 5 which excludes transport and storage.

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# The sensitivity assumes all non-power hydrogen demand is met by biomethane, leading to lower hydrogen storage, electrolysers, and RES build-out

**KEY STORYLINES**

| | |
|---|---|
| **1** | **$H_2$ production:** The absence of non-power $H_2$ demand leads to much lower electrolyser and SMR-CCS build than in the Base case. Since the baseload non-power industrial demand is assumed to be met by biomethane rather than hydrogen, there is no new SMR-CCS build in both Counterfactual and Backbone cases. With the Backbone, more electrolysers can be built in high-RES zones such as Scotland, where cheaper hydrogen could be transported predominantly to the north of England where H2 to power demand is located. |
| **2** | **Hydrogen storage:** Hydrogen storage falls in this sensitivity due to reduced electrolyser build, stemming from the absence of non-power $H_2$ demand. With a Backbone, more storage—mainly northern salt caverns—is added as they can access cheaper hydrogen from additional Scottish electrolysers as well as supporting the extra CCGT $H_2$ build. |
| **3** | **Dispatchable generation:** There is a slight increase in CCGT-$H_2$ capacity relative to the Base case due to lower $H_2$ production costs as it is predominantly supplied by electrolysers. The Backbone enables slightly more economic CCGT-$H_2$ build by improving access to low-cost Scottish hydrogen. |
| **4** | **Electricity transmission network:** Transmission build in the sensitivity is largely unchanged from the Base case. As in the Base case, the Backbone allows surplus electricity in oversupplied zones to be converted to hydrogen and transported to demand centres, reducing the need for additional transmission. |
| **5** | **Electricity Storage:** 6-hour battery capacity is lower in the sensitivity compared to the Base case because batteries play a smaller balancing role in the absence of $H_2$ demand and are partly replaced by CCGT-$H_2$ using cheaper hydrogen. LDES also declines. With the Backbone, both 6-hour batteries and LDES fall further as electrolysers absorb more excess RES generation. |
| **6** | **Renewables:** Lower electrolyser build reduces RES viability, leading to less onshore wind and solar PV in the sensitivity compared to the Base case. The Backbone slightly reduces onshore wind further as hydrogen imports from the North increase. |

Refer to Annex for more details

# In Sensitivity 6, the Backbone has no impact on the overall system cost as all non-power hydrogen demand is assumed to be met by biomethane

## KEY MESSAGES

1 **Compared to the Base case:**

Compared to the Base case, the costs of Sensitivity 6 are higher by around £43 bn in the Counterfactual scenario and £48 bn in the Backbone scenario over the 35-year assessment period.

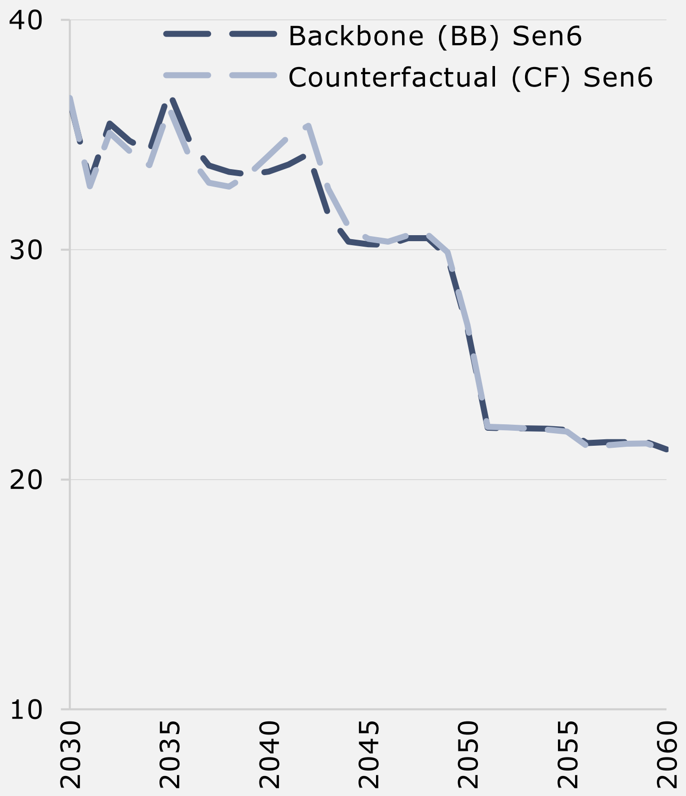
The main driver of the increase in costs is due to the biomethane supply to cover non-power industrial demand *(not part of the model optimisation process as was in sensitivity 5 for power demand)*. This outweighs the reduced costs from less SMR-CCS build along with less RES due to significantly lower $H_2$ demand. With the backbone in place, CCGT-H₂ operates more frequently than in the Base case, thereby displacing conventional gas-fired CCGTs.

2 **Sensitivity 6 BB-CF:**

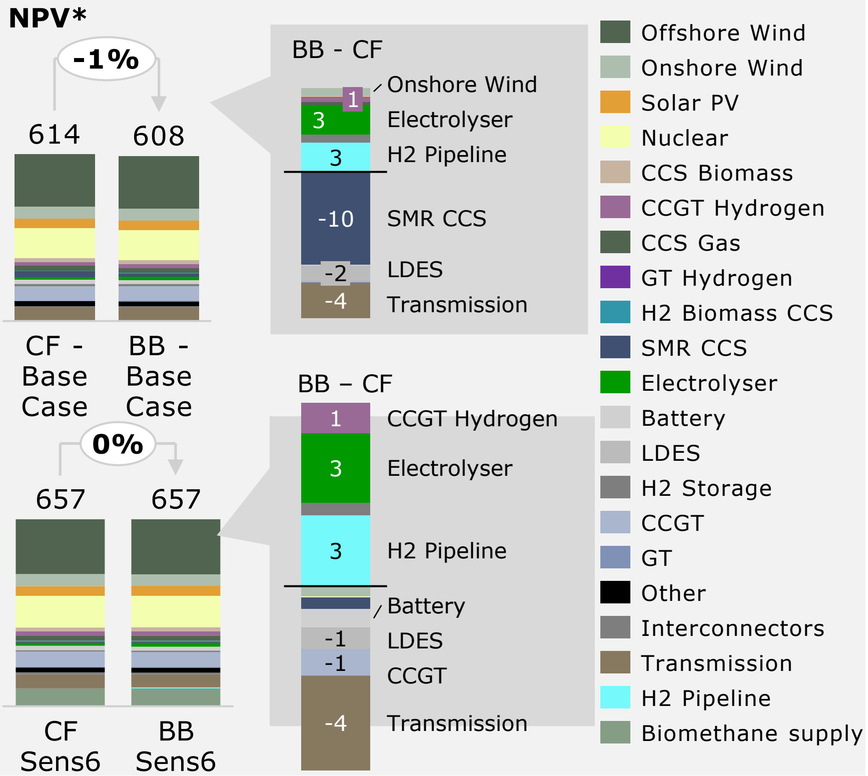
The addition of the backbone has almost no impact on the NPV of the total system cost. The reductions in LDES, transmission and CCGT costs are offset by the increase in CCGT $H_2$, electrolyser and pipeline costs across the 35-year period assessed.

## SENSITIVITY 6 SYSTEM COST COMPARISON - CF VS BB WITHIN SENSITIVITY

ANNUAL SYSTEM COST (BN £, REAL 2023)




TOTAL SYSTEM COST BY TECH – BB & CF COMPARISON (BN £, REAL 2023)




Notes: CF – Counterfactual scenario, BB – Backbone scenario. Where there is no "Sen" mentioned with CF or BB then this refers to the Base case.
* NPV is on a 35-year (2025-2060) period using a rate of 3.5% for the first 30 years and 3% for the last 5 years

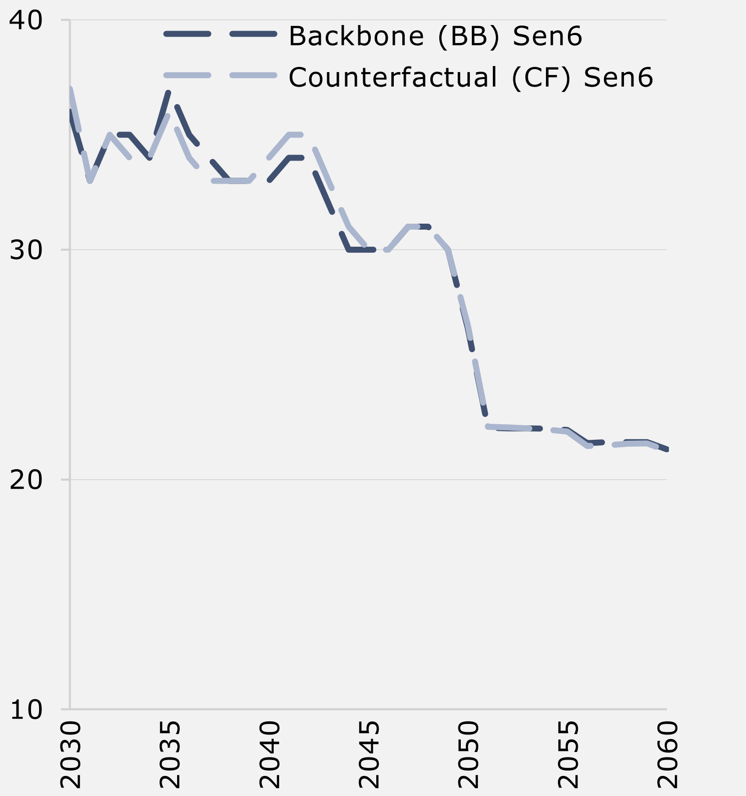
# Sensitivity 6 results in the highest total system cost between the sensitivities due to the high cost of satisfying non-power demand

## KEY MESSAGES

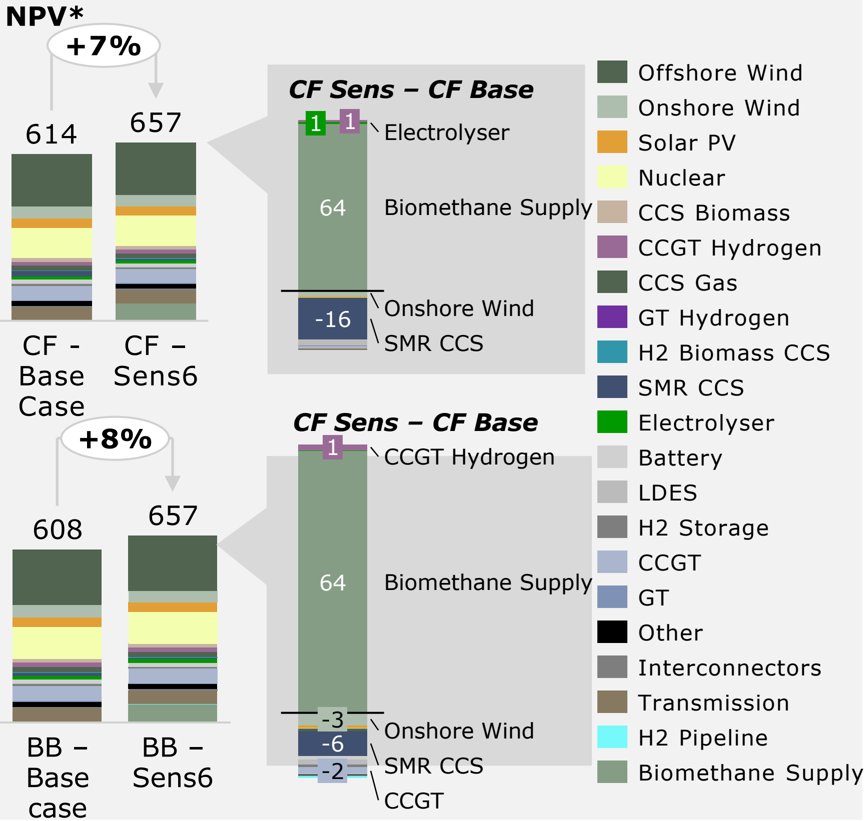
| | |
|---|---|
| **1** | Compared to the Base case, the costs of sensitivity 6 are higher by around £43 bn in the Counterfactual scenario and £48 bn in the Backbone scenario. |
| **2** | The main driver of the higher system cost is the increased biomethane supply required to meet non-power industrial demand. These additional biomethane costs outweigh the reductions in SMR-CCS build and the lower RES deployment resulting from significantly reduced hydrogen demand. |
| **3** | Biomethane costs in industry were derived externally to the model by multiplying the biomethane cost curve in the Annex by the industrial demand trajectory assumed in this sensitivity; these costs were then added as an exogenous input to the system-cost comparison. |

## COMPARISON OF CF AND BB SYSTEM COSTS TO THE BASE CASE

ANNUAL SYSTEM COST (BN £, REAL 2023)




TOTAL SYSTEM COST BY TECH – BB & CF COMPARISON (BN £, REAL 2023)

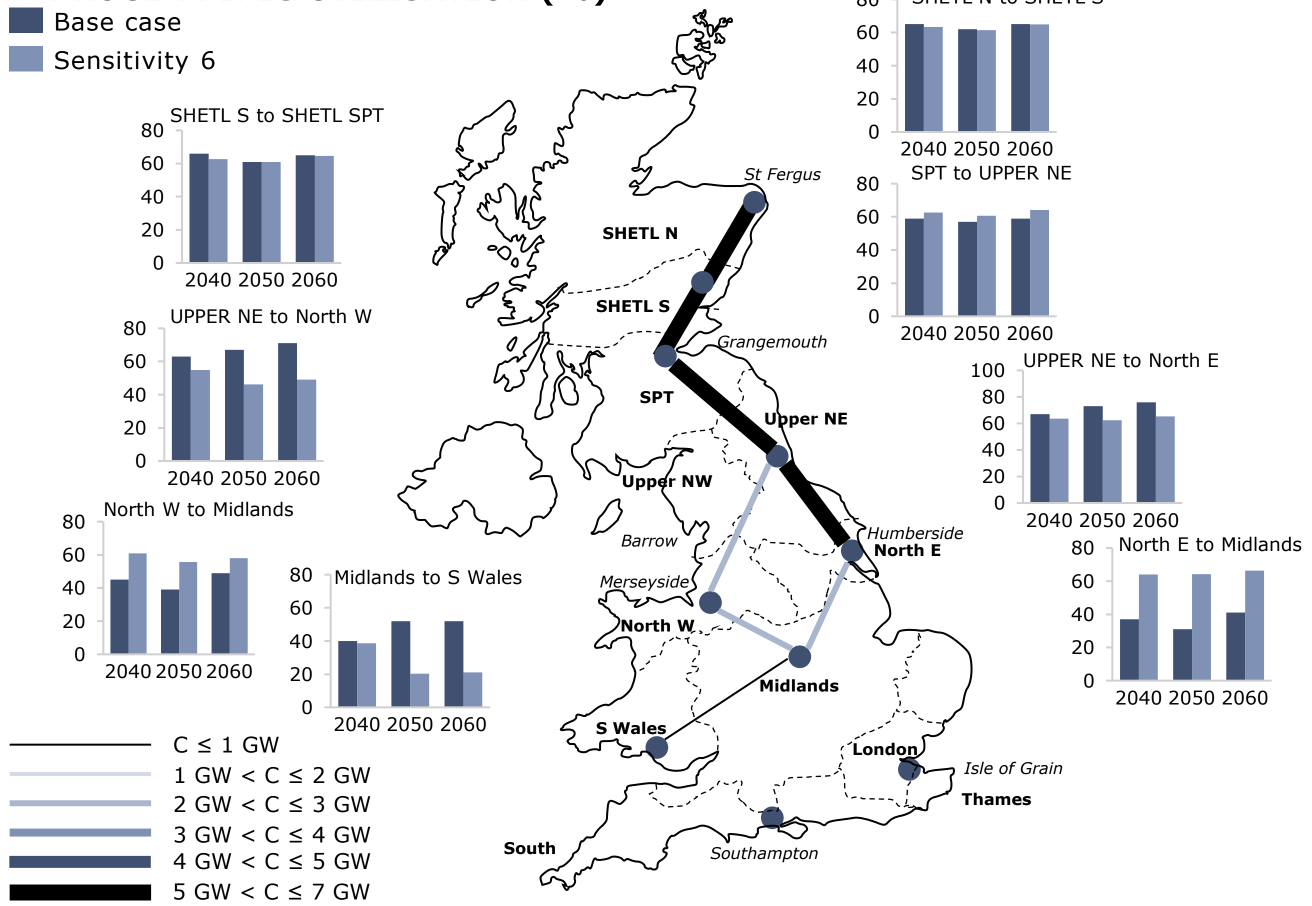



Notes: CF – Counterfactual scenario, BB – Backbone scenario. Where there is no "Sen" mentioned with CF or BB then this refers to the Base case.
* NPV is on a 35-year (2025-2060) period using a rate of 3.5% for the first 30 years and 3% for the last 5 years

# Scottish pipelines' utilisation is similar with the Base case, but utilisation towards the Midlands increases due to more CCGT $H_2$ build

## HYDROGEN PIPES UTILISATION (%)




## COMMENTARY

- The Scotland–North England corridor remains highly utilised in Sensitivity 6, as electrolyser build is still concentrated in Scotland.
- Scottish pipeline capacity is similar to the Base case through to 2040 before plateauing, while the Base case capacities increase slightly by 2050. This leads to a situation where the Scottish pipeline utilisation in the sensitivity are broadly similar to the Base case even with no non-power demand.
- Utilisation of pipelines within the Northern English zones as well the pipe from Midlands to South Wales is lower due to the absence of non-power hydrogen demand, as this will instead be met by biomethane.
- Pipeline utilisation to the Midlands zone from the North W and North E is higher in the sensitivity compared to the Base case as CCGT-H2 plants are built there, in order to be closer to demand.

# Stable baseload non-power $H_2$ demand is the main prerequisite for backbone value, removing it greatly reduces the backbone's benefits

**Sensitivity insights**

- Within Sensitivity 6, the exclusion of industrial hydrogen demand results in near identical system cost outcomes with and without the Backbone, indicating no marginal value from its deployment under these conditions.
- Because SMR-CCS reduction drives the cost savings in other sensitivities, removing non-power hydrogen demand sharply lowers SMR-CCS reliance. With little SMR-CCS left to displace, the Backbone yields no cost savings, making BB and CF similar in total system cost.

**Limits of the sensitivity**

- Future biomethane costs could shift as demand grows, depending on whether scaling unlocks efficiencies or requires higher-cost marginal feedstocks.
- It treats biomethane as fully interchangeable with hydrogen across industry and transport, which is not true for all processes.
- Biomethane is excluded from power generation, so potential roles in balancing, peaking, and system flexibility — and interactions with hydrogen-fired generation — are not captured.
- Biomethane production is implicitly assumed to reach demand where demand exists, ignoring geographic mismatches, network limitations, and additional transport or upgrading infrastructure needs.

**Wider risks beyond the sensitivity**

- Industrial fuel choices remain uncertain, with sectors likely to adopt hydrogen, biomethane, electrification, and CCS at different rates depending on costs, retrofit needs, regulation, and supply conditions—making long-term hydrogen demand inherently variable.
- Biomethane supply is constrained by feedstock limits and competing uses across heat, power, transport and industry, meaning large-scale deployment may be more limited or costly than the sensitivities imply.
- As fossil gas usage declines, the costs of operating, maintaining, and eventually decommissioning the gas network must still be recovered from a shrinking user base. This creates long-term regulatory and affordability challenges that intersect with any shift toward biomethane or hydrogen.

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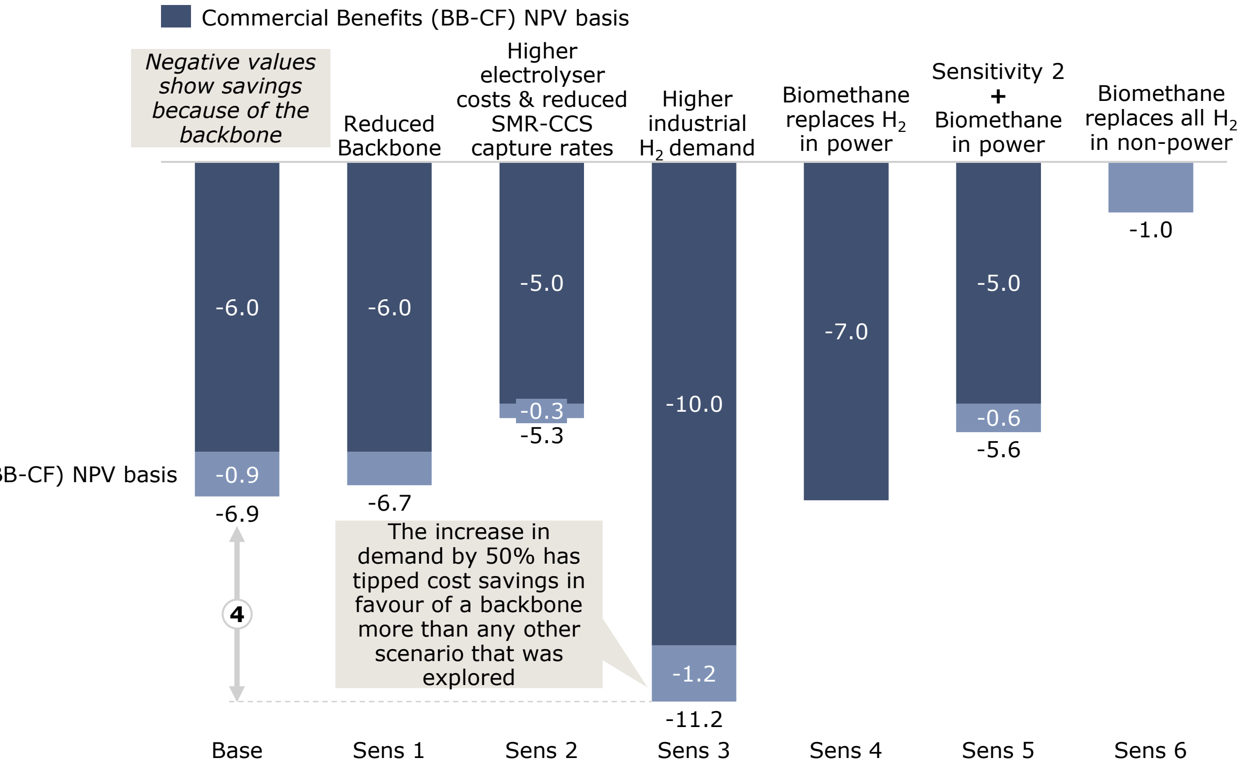
# Across *most* sensitivities, the Backbone consistently delivers system cost savings, with the greatest benefits seen under the higher $H_2$ demand scenario

**TOTAL SYSTEM COSTS BENEFITS (BB-CF) NPV BN £, REAL 2023**



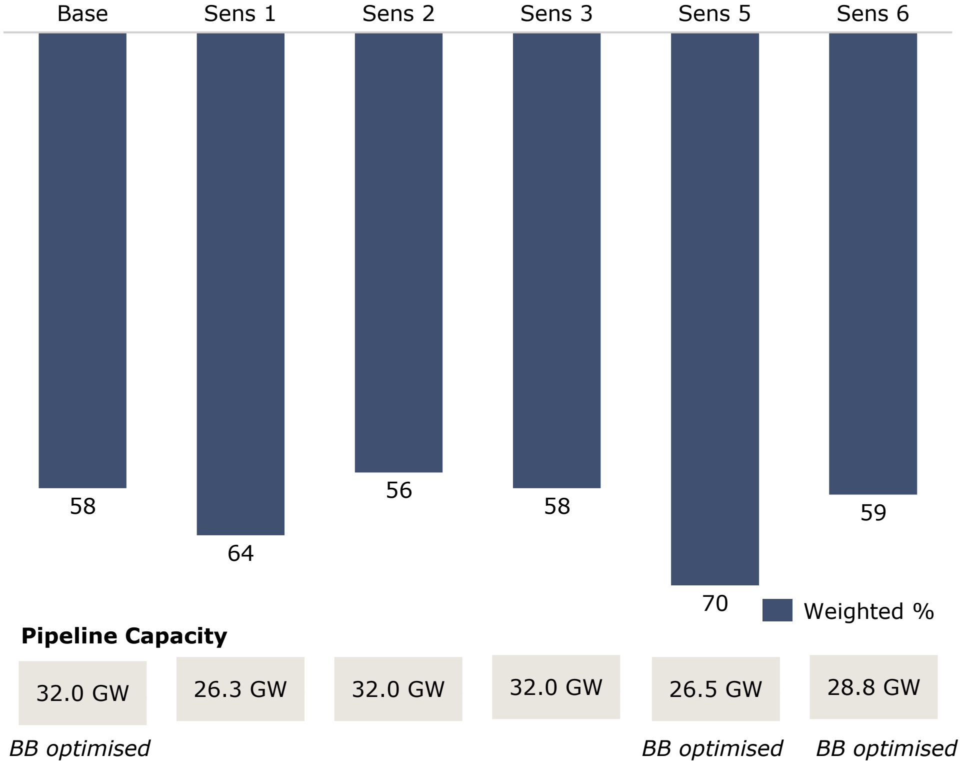

***All sensitivities except 6, deliver ~1–2% NPV system-cost savings versus their Counterfactuals.***

| Sens | Key messages |
|---|---|
| **1.** | – A reduced BB can deliver the same benefits over the modelled period in aggregate as the Base case as long as the main branches (Scotland to Northeast England) are in place in a timely fashion |
| **2.** | – Higher electrolysis costs shift supply toward SMR-CCS, so the backbone enables only limited—and more expensive—electrolysis which also results in less social carbon cost savings. |
| **3.** | – Out of all sensitivities system cost savings are greatest due to the BB serving a higher level of non-power demand.<br>– The BB enables demand centres to benefit from lower-cost $H_2$ rather than blue hydrogen from SMR-CCS and it is this reduction that drives the major portion of the savings. |
| **4.** | – The backbone's savings in the sensitivity mainly stem from lower variable OPEX, as biomethane is costlier while the backbone further reduces hydrogen fuel costs.<br>– A coordinated twin-track approach could still unlock marginal system-wide benefits. |
| **5.** | – Sensitivity 5 has a similar level of benefits as Sensitivity 2 while the enablement of biomethane in power leads to greater social cost of carbon savings compared to Sensitivity 2. |
| **6.** | – With no additional SMR-CCS built in this sensitivity, the backbone cannot deliver savings from reduced SMR-CCS variable OPEX, resulting in no system savings. This highlights the importance of non-power hydrogen demand where the savings stem from shifting supply from blue to cheaper green hydrogen. |

Backbone optimisation was only performed for the base case. It is therefore reasonable to assume that, had Sens. 2 also been iterated, pipeline capacities would have been reduced further relative to the base case, yielding slightly higher savings. No carbon-intensity value has been assigned to biomethane-fired CCGTs, as biomethane is treated as carbon-neutral.

# Sensitivity 5 shows the highest utilisation due to the smaller backbone capacity and higher flows from Scotland to Northeast England

## CAPACITY WEIGHTED AVERAGE PIPELINE UTILISATION, 2050 (%)




***Sensitivity 5 has the highest pipeline utilisation; this is due to its lower capacity build out and more concentrated electrolyser build in Scotland***

| Sens. | Key messages |
|---|---|
| **1.** | – Reducing the backbone capacity build-out leads to a more concentrated use of the available pipeline capacity for hydrogen transport between zones. The resulting increase in capacity-weighted average utilisation mainly reflects the removal of under-utilised capacity, leaving only the more actively used parts of the network. |
| **2.** | – The higher electrolyser costs lead to less electrolyser build-out, resulting in lower pipe utilisation in comparison to the Base case, although this effect is minimal. |
| **3.** | – The increase in hydrogen demand does not significantly impact overall pipeline utilisation compared to the Base case. However, certain zone boundaries show higher utilisation, while others experience a decrease. |
| **5.** | – Sensitivity 5 has the highest utilisation due to a smaller optimised backbone where pipelines in the south are reduced/removed.<br>– There will be more utilisation in the Scottish pipelines due to a more concentrated build of electrolysers in Scotland. |
| **6.** | – In Sensitivity 6, the smaller optimised backbone has a broadly similar utilisation level compared to the Base case as hydrogen production is predominantly supplied by electrolysers due to the absence of non-power industrial demand.<br>– Lower pipeline utilisation in the northern English zone is offset by higher utilisation of pipes to the Midlands zone. |

The biomethane sensitivity (Sensitivity 4) was modelled outside BID3 and without observing pipeline utilisation, so cannot be included within this analysis

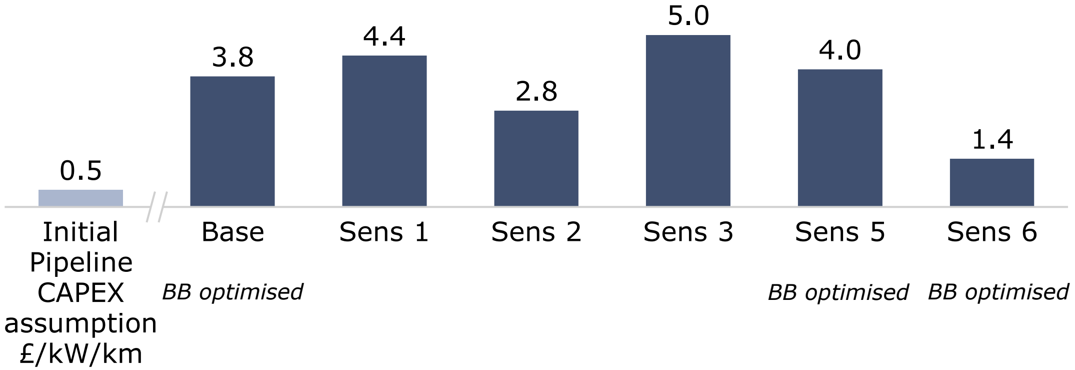
 

# Sensitivity 3 shows the greatest resilience to higher backbone costs because it delivers the largest system benefits because of the backbone

## BACKBONE COMMERCIAL ASSUMPTIONS

| | | The value of pipeline capex which would cause the BB & CF scenarios to equalise (no benefits) | | | | | |
|---|---|---|---|---|---|---|---|
| **Parameter** | **Base case assumption** | **Base case** | **Sens 1** | **Sens 2** | **Sens 3** | **Sens 5** | **Sens 6** |
| **Pipeline CAPEX** £/kW/km | **~0.5** | **~1.9** | **~2.2** | **~1.4** | **~2.5** | **~2.0** | **~0.7** |
| **Pipeline fixed OPEX** £/kW/km/y | 0.0033 | *No change* | | | | | |
| **Pipeline + Compressors CAPEX** | =Pipeline CAPEX *~1.4 | | | | | | |
| **Compressor OPEX** £/Y | 1.7% of compressor capex values | | | | | | |

## BACKBONE COST-INCREASE TOLERANCE NEEDED TO BREAKEVEN WITH SENSITIVITY COUNTERFACTUALS (X TIMES BASE CASE CAPEX ASSUMPTION)




**COMMENTS**

- There is high uncertainty around pipeline CAPEX, with a wide range of CAPEX estimates. In order to understand how this uncertainty around the backbone costs could impact the key results of this study, **we have modelled how much pipeline CAPEX could increase before the backbone's economic benefits (including social cost of carbon benefits) are fully eroded in each sensitivity**. In the Base case, the backbone remains cost-effective even if CAPEX rises to ~3.8× the assumed level, indicating a level of resilience to higher infrastructure costs proportional to its level of benefits.
- Sensitivity 3 has the highest tolerance level given that it exhibits the greatest level of benefits compared to its Counterfactual (including social cost of carbon savings). This sensitivity is characterised by the greatest level of industrial demand – meaning the removal of SMR-CCS from its Counterfactual because of the backbone is most substantial. Savings are mainly driven by less SMR-CCS as curtailed RES is transformed into cheap $H_2$ through Scottish electrolysis and delivered to demand centres throughout GB.
- On the flip side Sensitivity 6 has the lowest tolerance as it will break even with its Counterfactual if CAPEX estimates increase by just 1.4 times the Base case assumption. This reflects the removal of non-power hydrogen demand which substantially reduces the benefits provided by the backbone.

Pipeline cost assumptions have been held constant across the modelling period
Benefits include Social cost of carbon savings

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# The Base case analysis showed that the commercial case for a hydrogen backbone is weak, although non-commercial benefits suggest greater potential

## NEEDS CASE FINDINGS

**Economic assessment of the needs case is weak as the backbone only marginally improves the total system costs**

- The NPV of total system cost savings (covering CAPEX, fixed OPEX and variable OPEX) under the Base case assumptions show little improvement with the inclusion of a backbone compared to under a Counterfactual case without a backbone
- Increasing backbone CAPEX to the upper literature range negates benefits and slightly favours the Counterfactual.

**Non-commercial benefits were quantified after stakeholder engagements and discussions with NESO**

- Including non-commercial benefits gives a fuller view of system value.
- In addition to £6 bn in total system cost savings, the backbone delivers an estimated £920 million (NPV) in societal carbon cost reductions, bringing total quantified benefits to just under £7 bn.

**Unmonetized impacts indicate additional potential benefits**

- The Backbone cuts curtailment, increases green hydrogen production, and reduces gas reliance which strengthens resilience and increases the competitiveness of industrial hydrogen users by lowering the hydrogen price.
- It bring regional redistribution of GVA and jobs with minimal benefits in terms of total GVA or jobs.
- Significant electrolyser build-out could however create regional water stress, although national-level risk remains low. More detailed local analysis is recommended.

**A hydrogen backbone offers only limited economic justification, with marginal, assumption-dependent benefits that face significant risks and uncertainties**

- There is not a strong economic needs case for a hydrogen backbone over the Counterfactual
- Non-commercial benefits highlight further value that may be realised—potentially greater under sensitivities—pending deeper analysis.
- These marginal benefits accrue gradually over 35 years and depend on a set of assumptions that could be threatened by risks and barriers at every stage of development and implementation.

# The NPV of total system cost under all sensitivities shows improvement with the inclusion of a backbone with savings of 1%~2%

## NEEDS CASE FINDINGS

**A backbone consistently offers limited economic justification across all sensitivities, including with the introduction of biomethane**

- Across all cases with non-power hydrogen demand, the backbone delivers around 1–2% NPV system-cost savings versus the Counterfactual.
- A dual biomethane–hydrogen future can still justify a backbone under these conditions, although its value remains sensitive to increases in backbone costs.
- There is potential for biomethane to play an interim role while $H_2$ industrial demand ramps up.

**The Scotland → NE England corridor represents the lowest regret pipeline**

- The backbone delivers the greatest system savings when strong industrial hydrogen demand allows pipeline build to displace transmission reinforcements, and low-cost Scottish electrolysis displaces SMR-CCS and LDES—making the Scotland-to-NE England corridor consistently the most valuable part of the system.
- Across sensitivities, this pipeline branch delivers the majority of benefits as it connects renewable resource-rich Scotland with major industrial demand in northern England.

**Backbone savings are primarily driven by reduced SMR-CCS deployment**

- Savings consistently come from the same three areas:(1) reduced SMR-CCS build and operation, (2) avoided electrical transmission reinforcements, and (3) less need for LDES —all of which outweigh the additional costs of the backbone and extra electrolyser build.
- Electrolysers in Scotland remain cost-effective even when electrolyser costs are high: Electrolytic hydrogen still displaces SMR-CCS because of abundant, low-cost wind and reduced curtailment, even when biomethane displaces hydrogen in power.

**Backbone savings fade only when non-power hydrogen demand is removed**

- Across the sensitivities industrial demand is modelled as being supplied by blue $H_2$ in the CF, any reduction in that demand directly decreases blue $H_2$ requirements.
- Eliminating industrial demand removes the fundamental driver of backbone utilisation, leaving almost no SMR-CCS to displace; the only remaining savings arise from the social cost of carbon.
- On the other hand, increasing industrial demand results in a situation where the backbone delivers the greatest benefits in commercial and non-commercial benefits.

# Realisation of the backbone's benefits are contingent upon tight coordination across policy, supply, and demand

## SENSITIVITIES

**The hydrogen backbone is a strategic enabler — but its success depends on coordinated delivery**

- The backbone is a system-level investment whose value depends on timing, policy alignment, and demand growth.
- The modelled benefits of the backbone only fully materialise under certain enabling conditions.
- Risk management in this context is about ensuring the enabling ecosystem (policy, regulation, social licence) moves in sync.

**Cost and demand are tightly linked — utilisation is key to economics**

- The backbone's viability will be sensitive to hydrogen throughput (demand ramp-up).
- This shows the need for parallel development of supply, demand, and infrastructure — none of them can lead or lag too much.
- Even if the BB is built efficiently and cheaply, it won't be economically justified unless there's sufficient demand and throughput to generate enough value-and consequently system cost savings.

**Delays cascade through the system**

- Broader risks such as public support, permitting, supply chains, could manifest as delays and a fragmented backbone. In reality, these cause major knock-on effects: slower hydrogen uptake, delayed decarbonisation, investment uncertainty, and potential for stranded or abandoned projects.
- This underscores the case for a phased, low-risk backbone strategy — supported by early action, stable and coordinated regulation, and strong stakeholder alignment.

**Policy and regulation are the levers that de-risk the whole system**

- Clear policy frameworks can amplify or dampen every other risk.
- Transparent, stable policy with a clear vision is an important risk mitigant.

  

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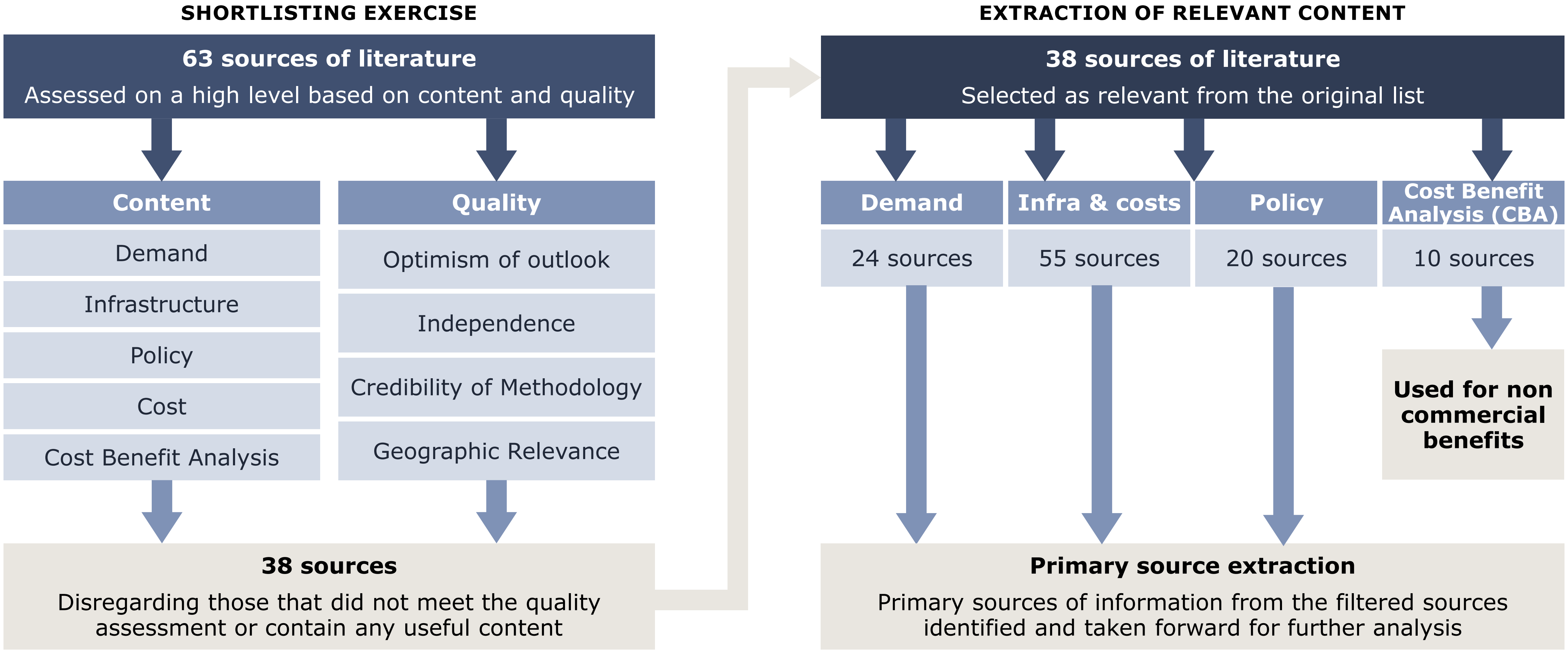
# For the literature review, sources were shortlisted and categorised followed by the extraction of selected information and primary source data



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# Of the publications that explore demand, there are 5 key sources that were identified as primary sources, with 3 sources viewed as most useful

| Publisher | Publication Name | Source | | | | |
|---|---|---|---|---|---|---|
| UKERC | Sensitivity analysis of net zero pathways for UK industry | | ● | | | |
| CCC / AFRY | Net Zero Power and Hydrogen: Capacity Requirements for Flexibility | | ● | | | ● |
| BEIS / AFRY | Benefits of long-duration electricity storage | | | ● | | ● |
| ICL | The Role and Value of $H_2$ in Future Zero-Carbon GB's Energy System | ● | | | ● | |
| Royal Society | Large-scale electricity storage | | | | | ● |
| DESNZ | Hydrogen production delivery roadmap | ● | ● | ● | | |
| Scottish Gov | Hydrogen Action Plan | ● | ● | | ● | |
| BEIS | Hydrogen Transportation and Storage Infrastructure | | ● | ● | | |
| ARUP | The potential role of a hydrogen network in Europe | | ● | ● | ● | |
| House of Lords | Long-duration energy storage: get on with it | | ● | | | ● |
| HUK | HUK Hydrogen to Power Report | | ● | | ● | |
| AFRY / Agora | No-regret Hydrogen | | | | | ● |
| National Gas | Project Union East Coast Re-Opener | | | | ● | |
| National Gas | Project Union North West Re-Opener | ● | ● | | ● | |
| National Gas | Project Union St Fergus to Teesside Re-Opener | | | | ● | |
| Cadent | HyNet North West: From vision to reality | | | | | |
| ECH | East Coast Hydrogen Delivery Plan | | | | ● | |
| ARUP | A vision for hydrogen in the Tees Valley | | ● | | | |
| Scottish Gov | Scottish Hydrogen Assessment | ● | ● | | ● | |

## Primary Sources

**FES** – 2020 Onwards

Provides credible demand data backed by and exploring multiple net-zero 2050 scenarios. Does not produce an independent view for NESO and will be soon updated.

**CCC** – Carbon Budgets

Well evidenced and very aligned with Net-zero. Most recent data (CB7) provides necessary hydrogen demand to reach Net-zero 2050. High transparency but some flaws in transport demand.

**DESNZ / BEIS** – NZIP Derived

Combines CCC and FES data with NZIP modelling in most recent data found in the $H_2$ Transport and Storage Networks Pathway. Limited transparency and only provides a range in most cases.

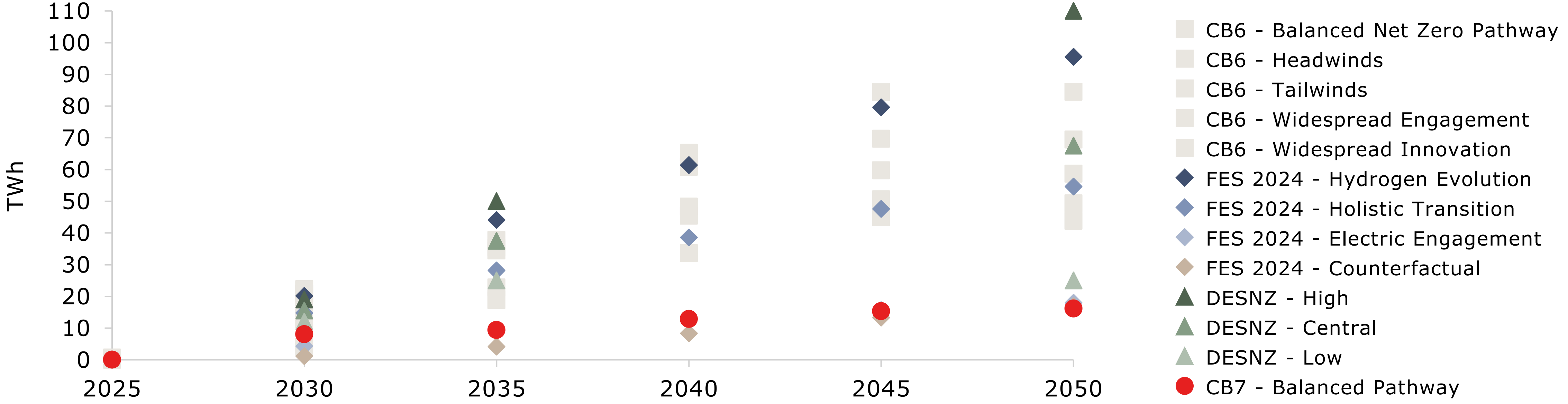
**Industry / Industry Groups** – Sub national

Predominantly driven by industry groups and consultancy giving bottom-up estimates for industrial clusters. Provides a good comparison for regional comparison but not national demand.

**AFRY** – Modelling / input contribution

Understood and trusted but in most cases not public. Non-power demand often from another source with power demand derived from AFRY modelling.

# For **Industrial** demand, the CCC's Balanced Pathway is roughly aligned with other conservative high electrification net zero scenarios




**FES 2024**

Range of scenarios reflecting hydrogen adoption at different levels

Most interestingly, the Electric Engagement scenario closely aligns with CB7's balanced pathway

This suggests agreement in volumes of hydrogen needed for net-zero

**DESNZ**

Provides the widest range with limited transparency on modelling assumptions.

By 2050 the low end of the range reaches a similar level to other scenarios further confirming minimum demand levels

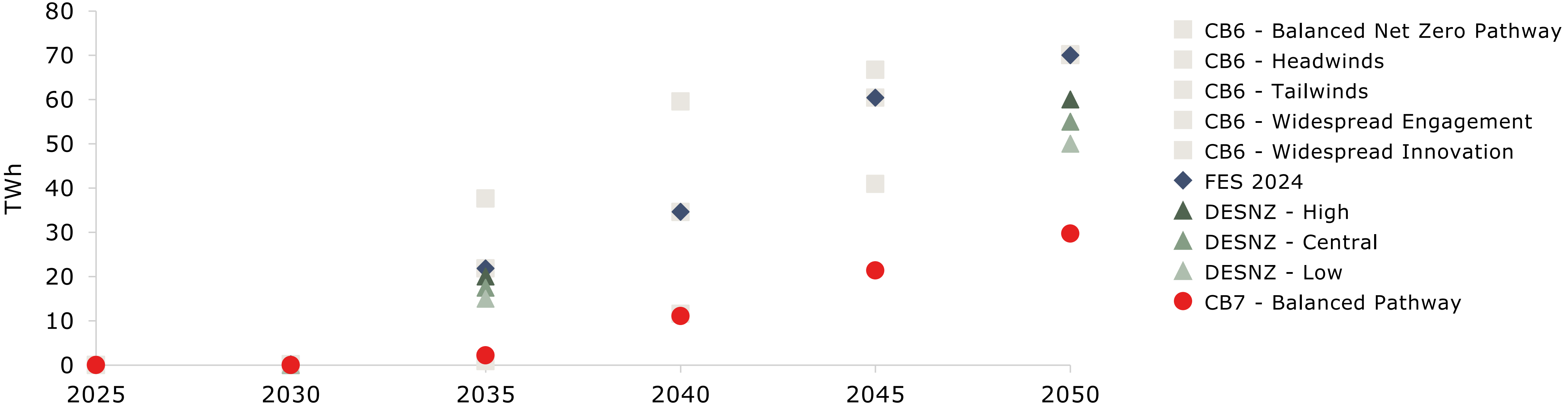
**7th Carbon Budget (CB7)**

Use of hydrogen in industry only when there is little to no alternative (feedstocks and high-temp heat)

Demand predominantly in chemicals, Non-Road Mobile Machinery (NRMM), glass, ceramics with some adoption in downstream steel processes

# In **Shipping**, the Balanced Pathway assumes all ammonia is imported while all e-methanol is domestically produced, creating some $H_2$ demand




◆ **FES 2024**

Very ambitious hydrogen demand for shipping

Consistent view across all scenarios other than the FES counterfactual which has no adoption

▲ **DESNZ**

Data from the Hydrogen Transport and Storage Networks Pathway provides a breakdown of transport demand

Ranges are given with the central estimated as the average

The range for shipping is very narrow and optimistic

● **7th Carbon Budget**

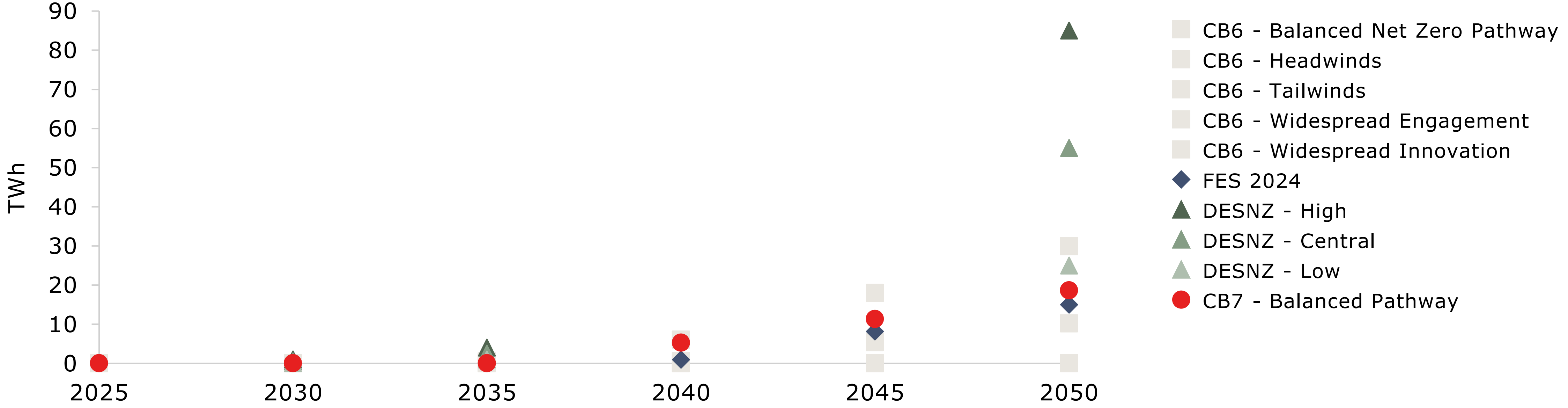
Ammonia (via imports) to meet 22% of shipping energy use by 2040

A further 17% of energy comes from domestic synthetic methanol, thus creating some hydrogen demand

A small proportion comes from direct use of hydrogen

# In **Aviation**, the Balanced Pathway's e-SAF demand fulfils the Power-to-Liquid requirement by 2040, whereas FES does not meet this target




**FES 2024**

Conservative estimate on hydrogen demand in aviation

Close to that on the 7th carbon budget but fails to meet UK SAF mandates Power-to-Liquid (PtL) obligation by 2040 of 3.5% fuel share

**DESNZ**

Wider range compared to shipping demand projection reflecting the uncertainty in hydrogen's use in aviation

Very optimistic suggesting a higher share of e-SAF or faster technological development for direct use

**7th Carbon Budget**

Unclear as to the exact numbers so deducted from other demands

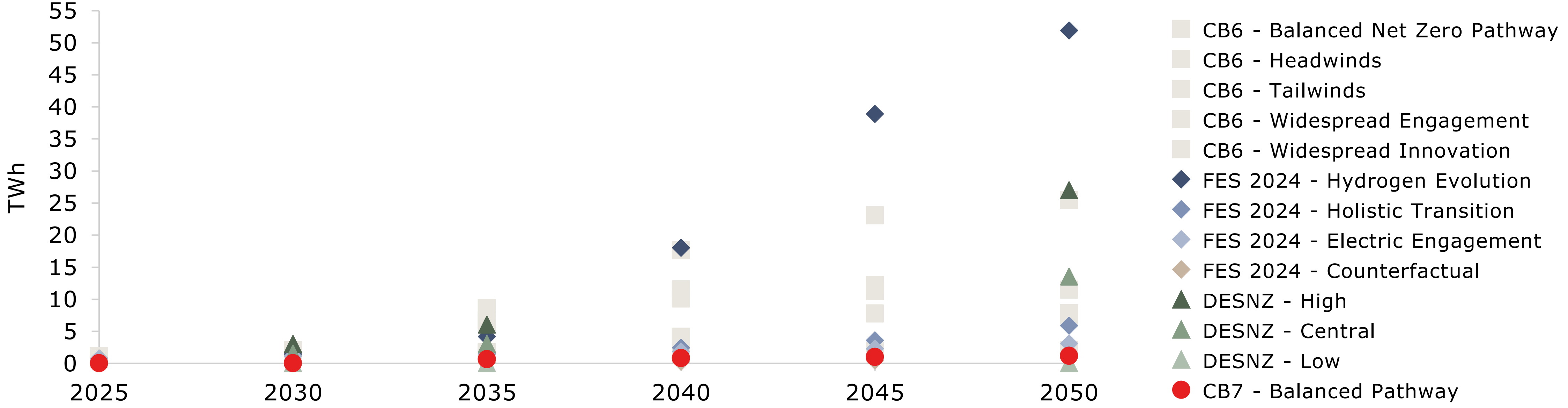
Assumes only domestic production

Meets the PtL obligation by 2040 but not before with the scenario reflecting a more realistic adoption timeline

Note: Aviation demand deduced from synthetic fuel production demand minus maritime demand producing some uncertainty.

# In **Surface** Transport, the CB7 Balanced Pathway shows very little demand only coming from hydrogen use in trains




**FES 2024**

Assumes hydrogen adoption predominantly in HGVs >26t

Varies level of adoption based on scenario

Hydrogen evolution stands out as unrealistic while other scenarios align more closely with CB7

**DESNZ**

Demand focused on adoption in HGVs and buses with the high linked to a 50% adoption in articulated HGVs and 30% adoption in buses

At the low end, we see no adoption of hydrogen in surface transport

**7th Carbon Budget**

Slow adoption of hydrogen into surface transport beginning 2035

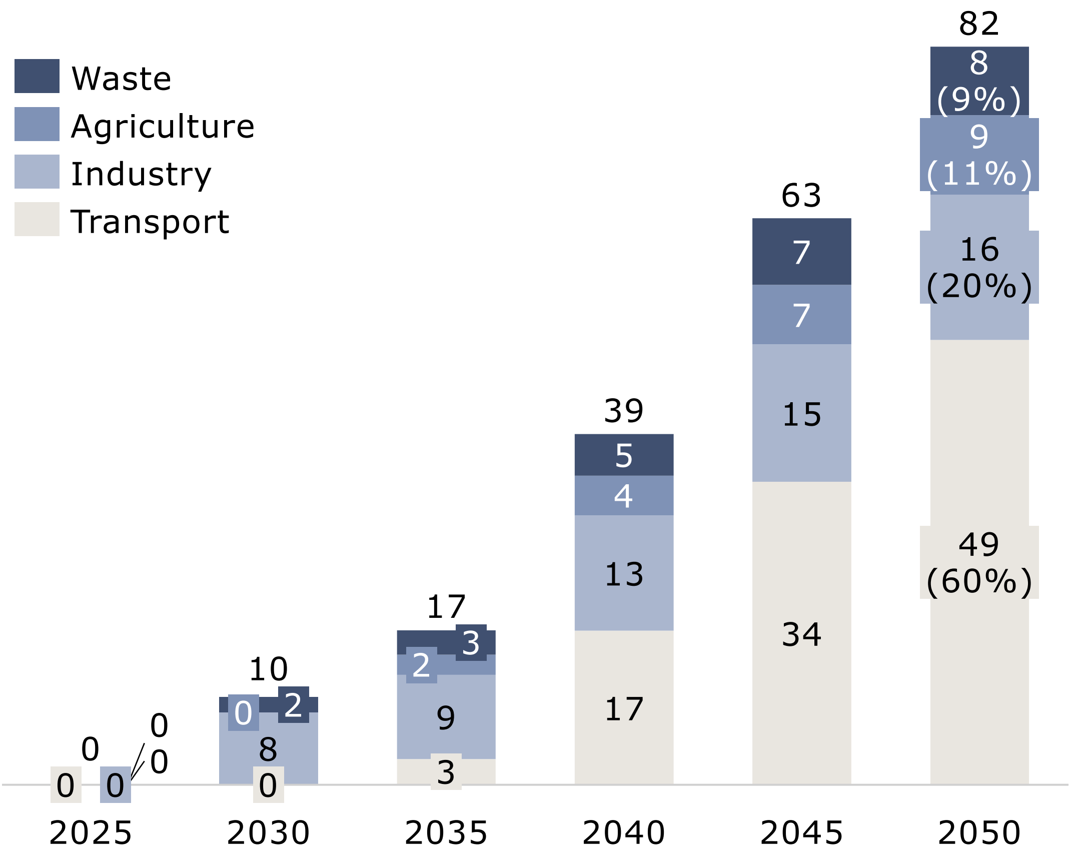
Demand only coming from trains not suitable for electrification

Leads to very little hydrogen demand in surface transport

# The Balanced Pathway also shows non-power demand from other sources

**BALANCED PATHWAYS NON-POWER DEMAND (TWH)**




**WASTE**

- The report does not clarify the use case for hydrogen in the waste sector where it is only used in Energy from Waste (EfW)
- The most likely reason for this demand is the high temperature requirements for EfW
- A second viable use is to inject hydrogen into the syngas to increase the methane concentration

**AGRICULTURE**

- The CCC assumes that hydrogen is only used in large agricultural machinery (e.g. NRMM) that is unable to electrify
- Initially decarbonisation will be through biofuels, before switching to hydrogen or hydrogen derived fuels in the long term.  This is the same approach taken to NRMM in industrial hydrogen demand.

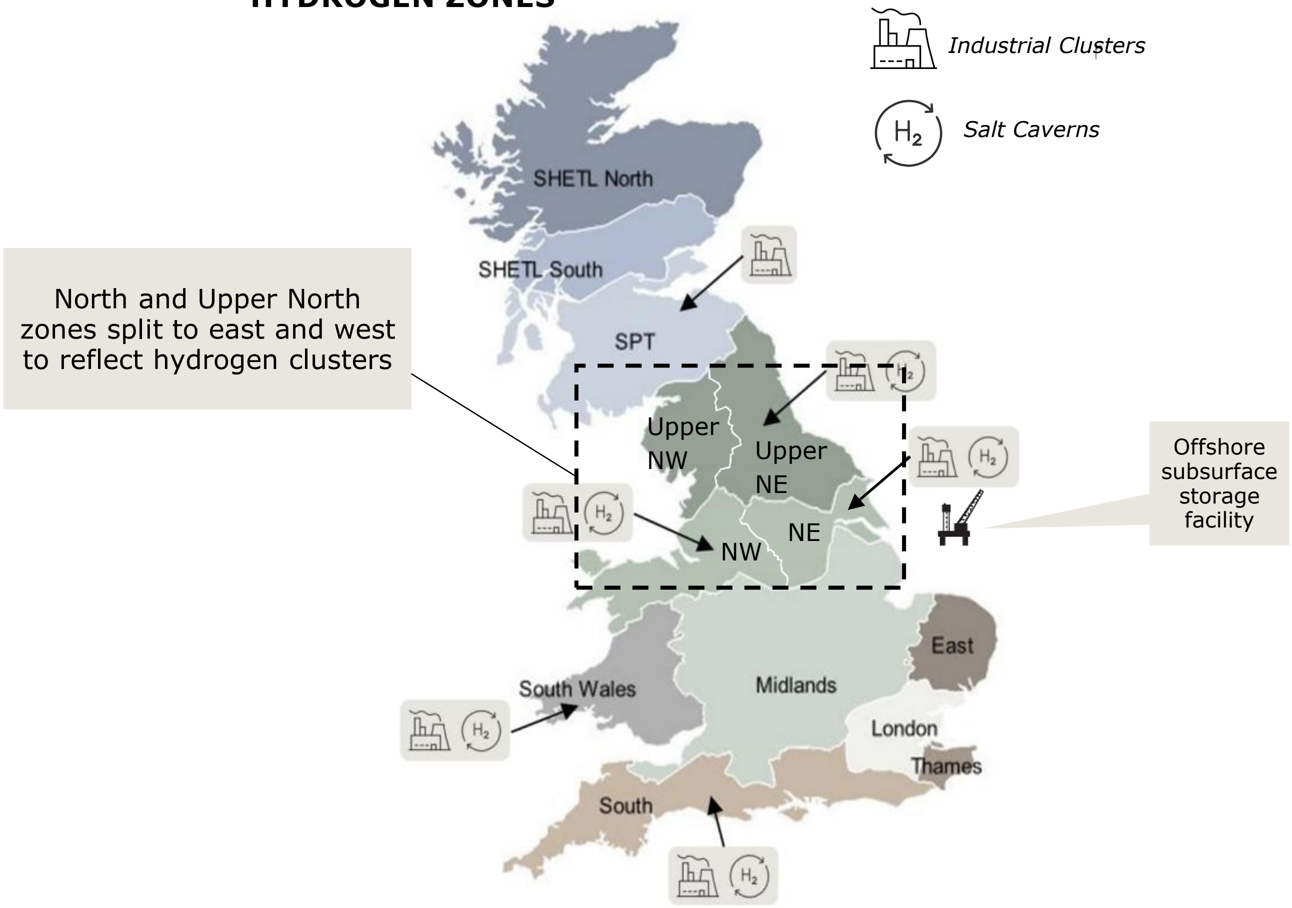
# Contents



# Hydrogen zones in our modelling

## POWER ZONES

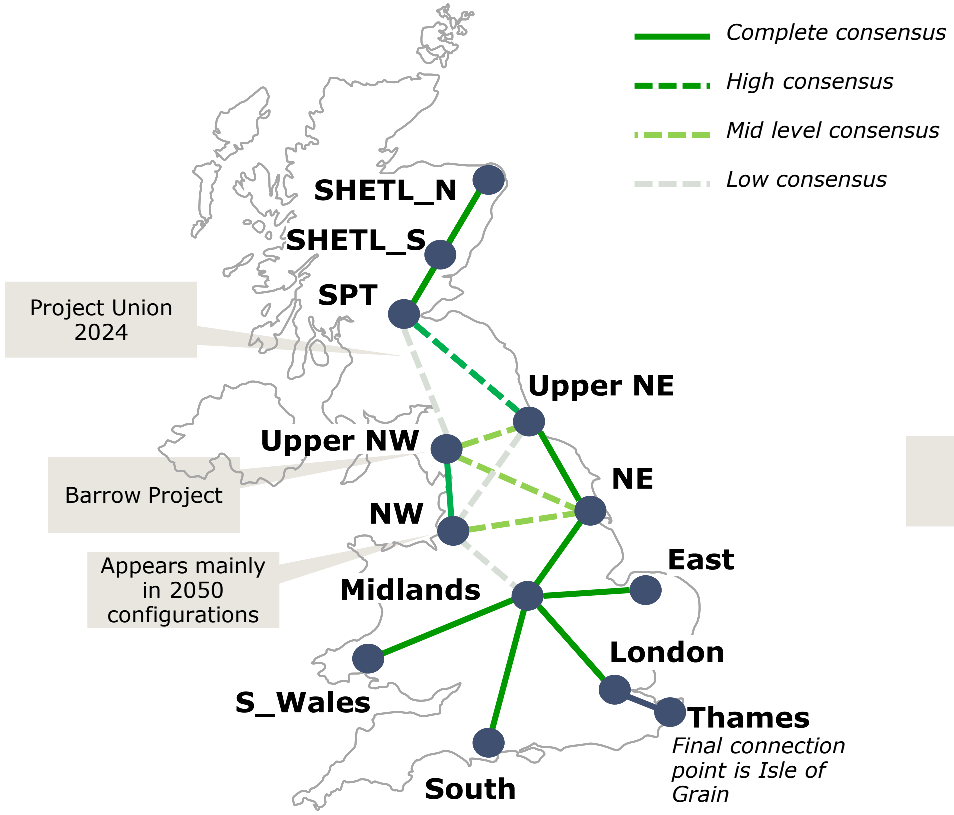

## HYDROGEN ZONES



# While there is broad consensus across the literature on certain parts of the $H_2$ backbone, there is notable variation in how some regions are connected

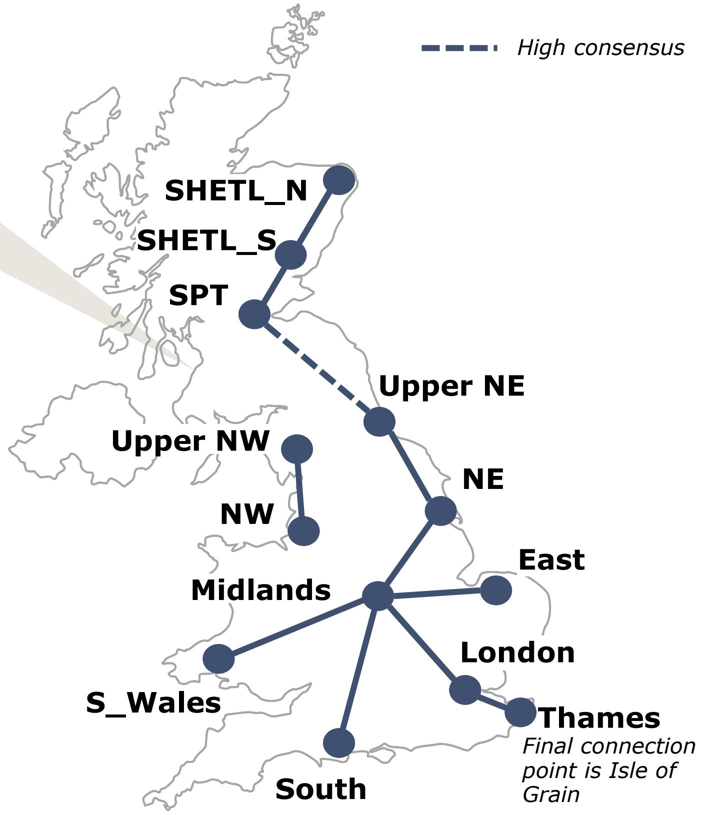
## HYDROGEN BACKBONE CONFIGURATIONS FROM LITERATURE




Highest consensus amongst selected literature

## PARTS OF THE HYDROGEN BACKBONE WITH CONSENSUS IN THE 2030S

The configuration of connections between Scotland and the Northwest clusters, as well as the linkage between the east and west coast clusters, differs across studies and remains open to interpretation.



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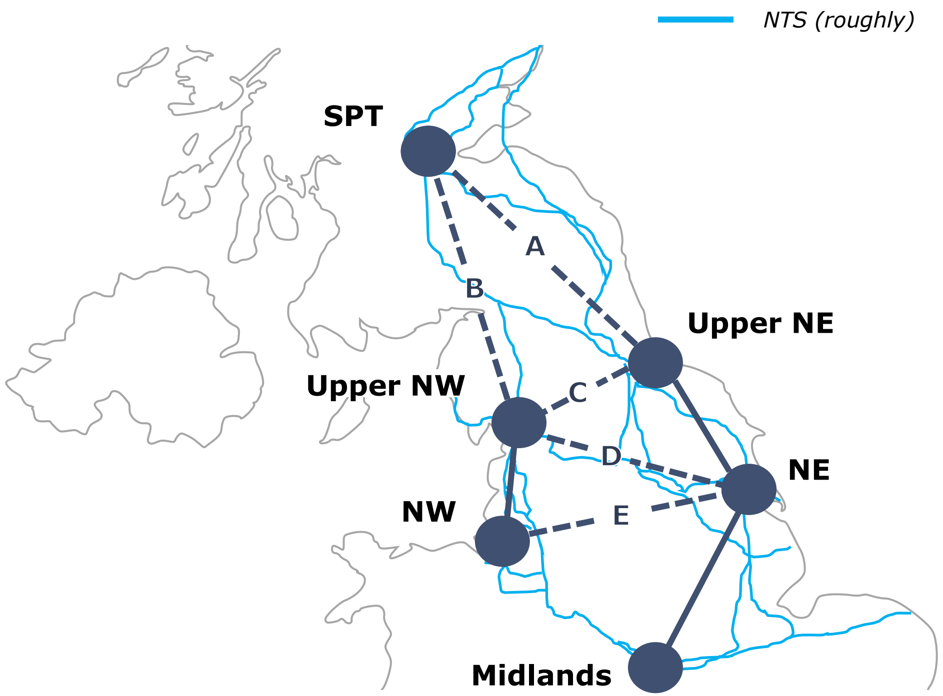
# As part of our assessment of the backbone, we considered how the $H_2$ network might either replace or run alongside existing NTS routes

## POTENTIAL ROUTES EXPLORED FOR THE HYDROGEN BACKBONE

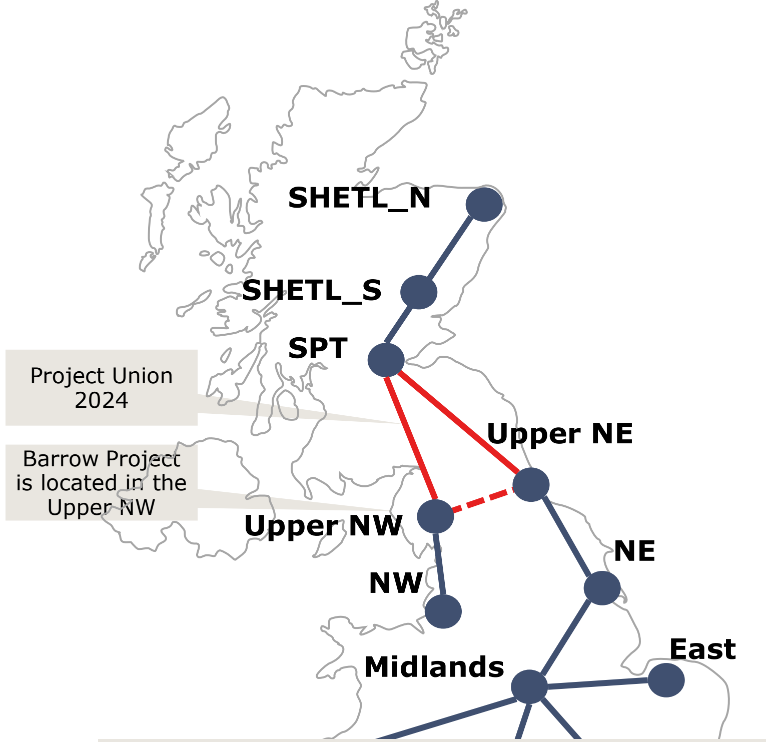



## KEY CONSIDERATIONS

- Either connection **A or B must exist** to transport hydrogen down from Scotland produced from excess wind
- If only one of these connections exists, then a connection from east to west would likely be established as seen in the literature:
  - Connection **C** could require reverse flow capabilities in the network depending on the presence of other pipelines such as A, B and D
- If connection C is not built, then connection **D** provides another viable route from east to west
- A direct connection via route **E** would require new infrastructure in proximity to or around a national park and major population centres. Therefore, it is unlikely.
- As well as flow from Scotland, the connections and their respective capacities in either direction with also be influenced by the presence of storage along both coasts

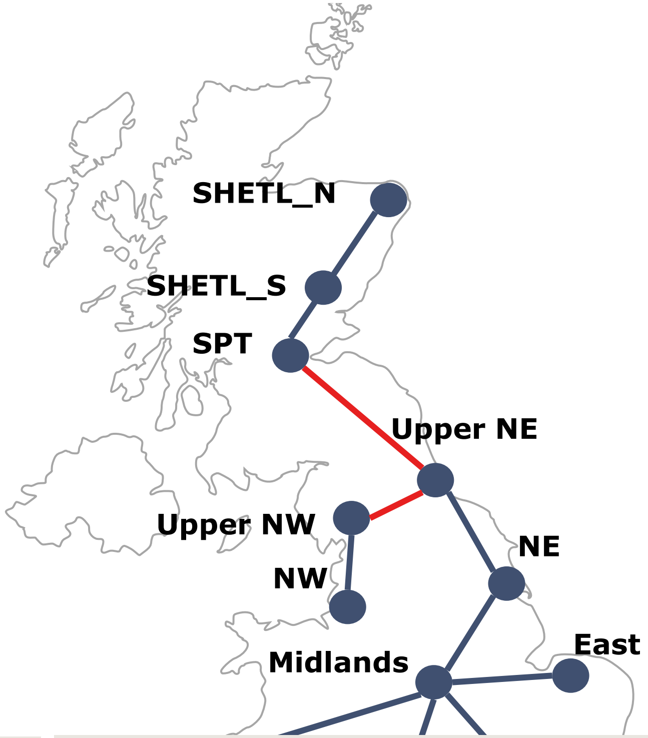
# Several sources show varying configurations of the backbone, with three major deviations in routes in the North

## Interpretation A



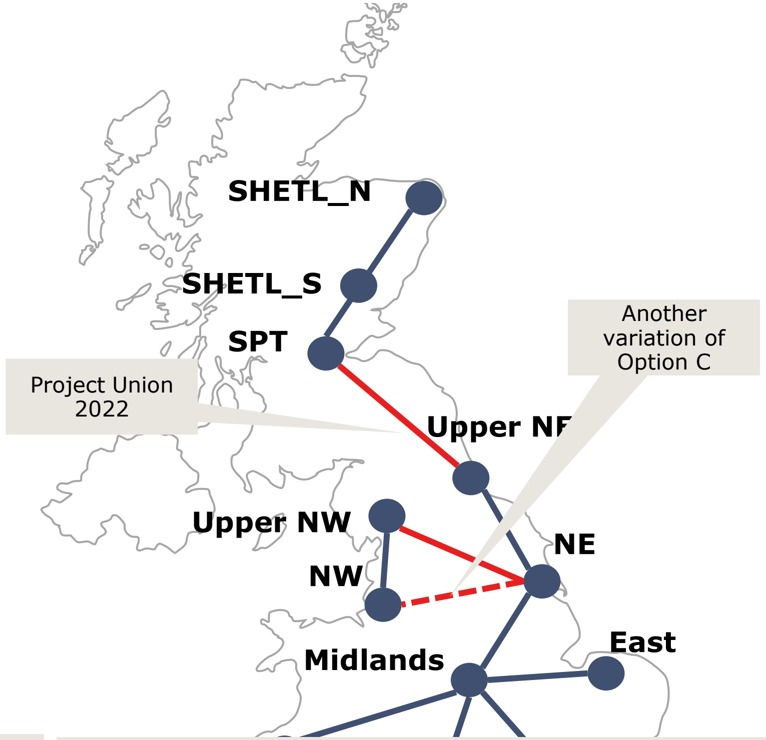

In this configuration the line to Upper NE is split in the Upper NW region

## Interpretation B




In this configuration shown by several sources, the Upper NE connects down to the NW cluster by passing through Upper NW which also connects the Barrow Hydrogen Project

## Interpretation C




Looking at the maps of the NTS pipelines it is evident that there is no existing direct NE to NW pipeline, however some sources have shown this connection (dotted line)



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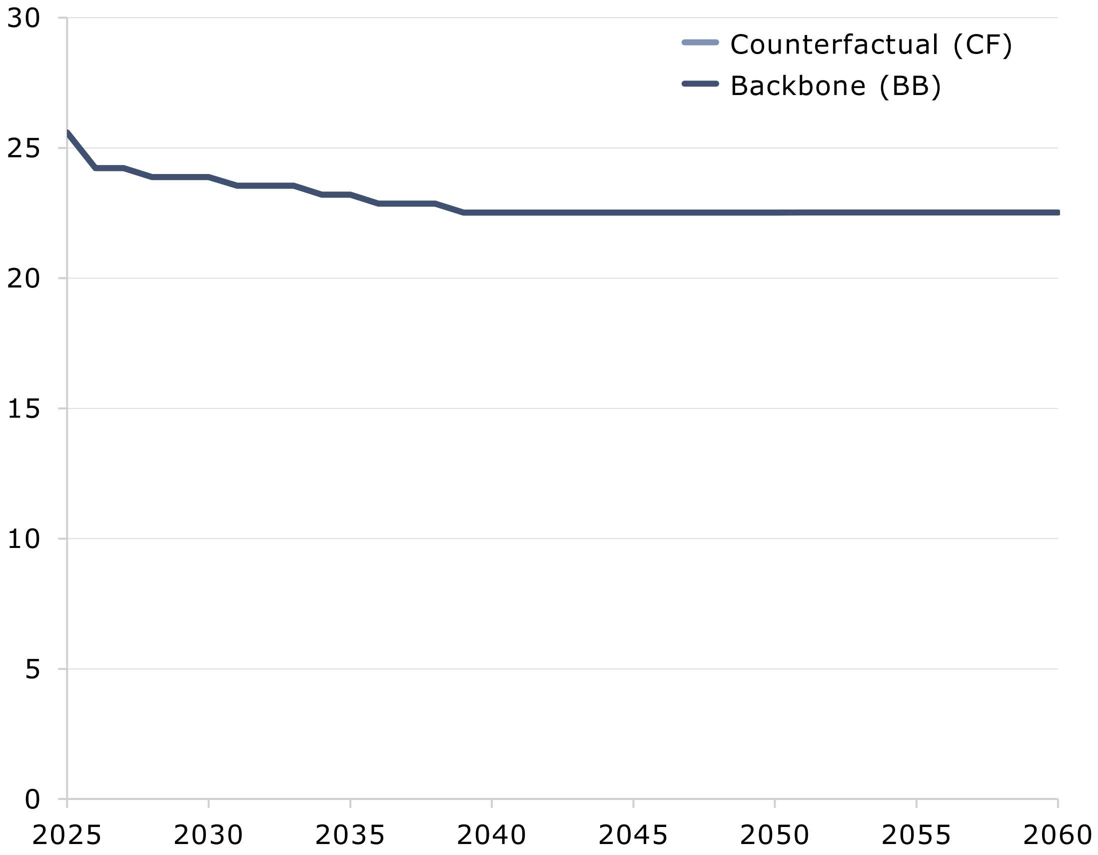
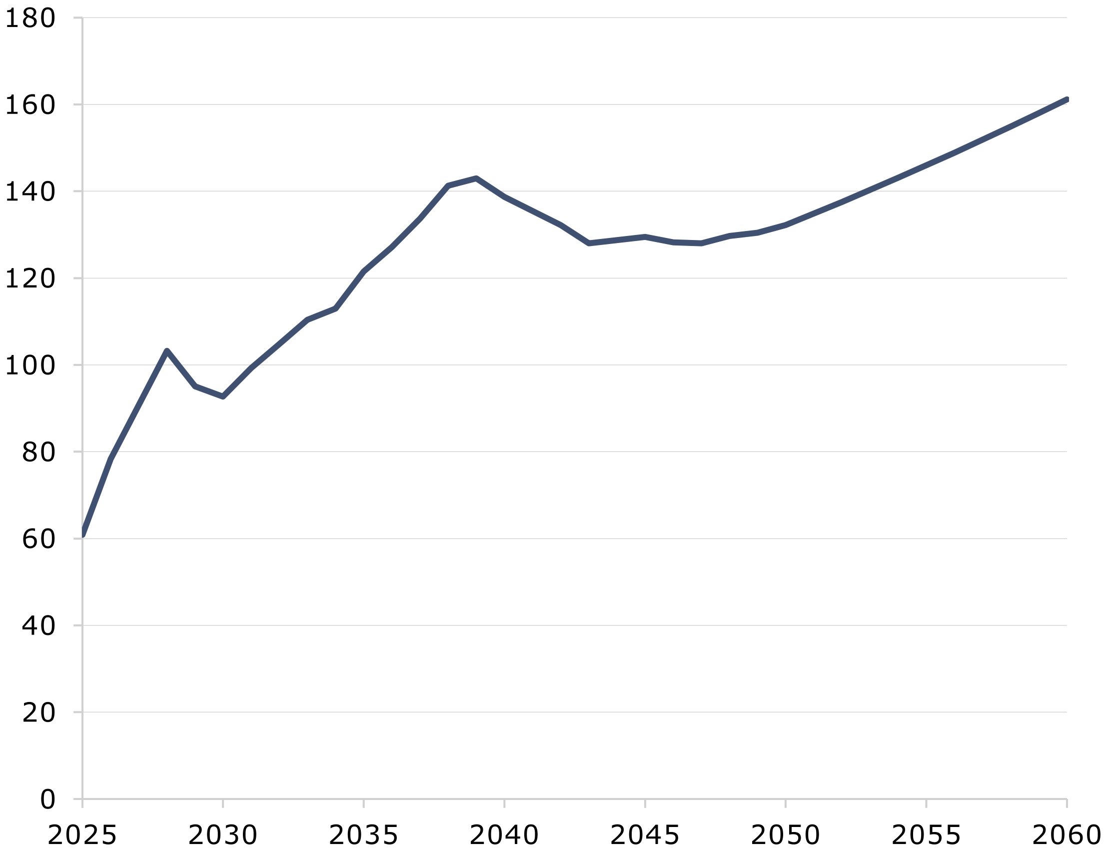
# Both Base cases use the same gas and carbon price projections: gas prices stay relatively flat, while carbon prices rise rapidly in future

**GAS PRICES (REAL 2023 £/MWH)**



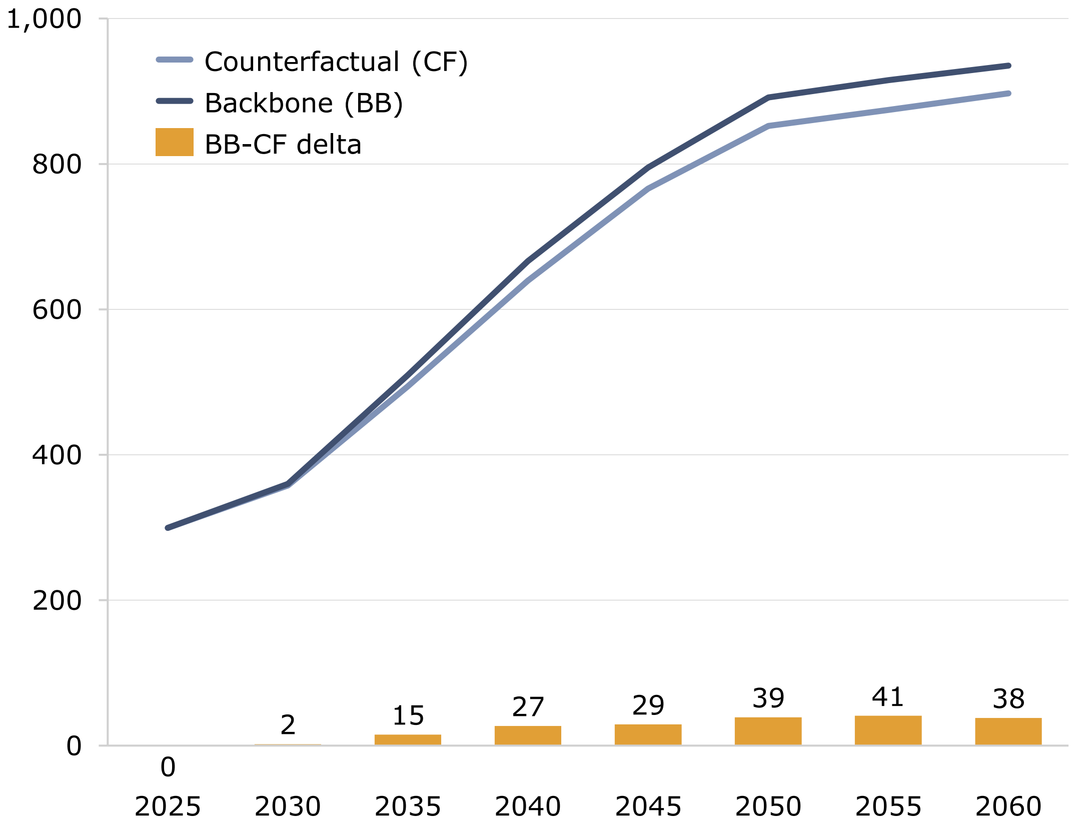

**$CO_2$ PRICES (REAL 2023 £/TONNE)**



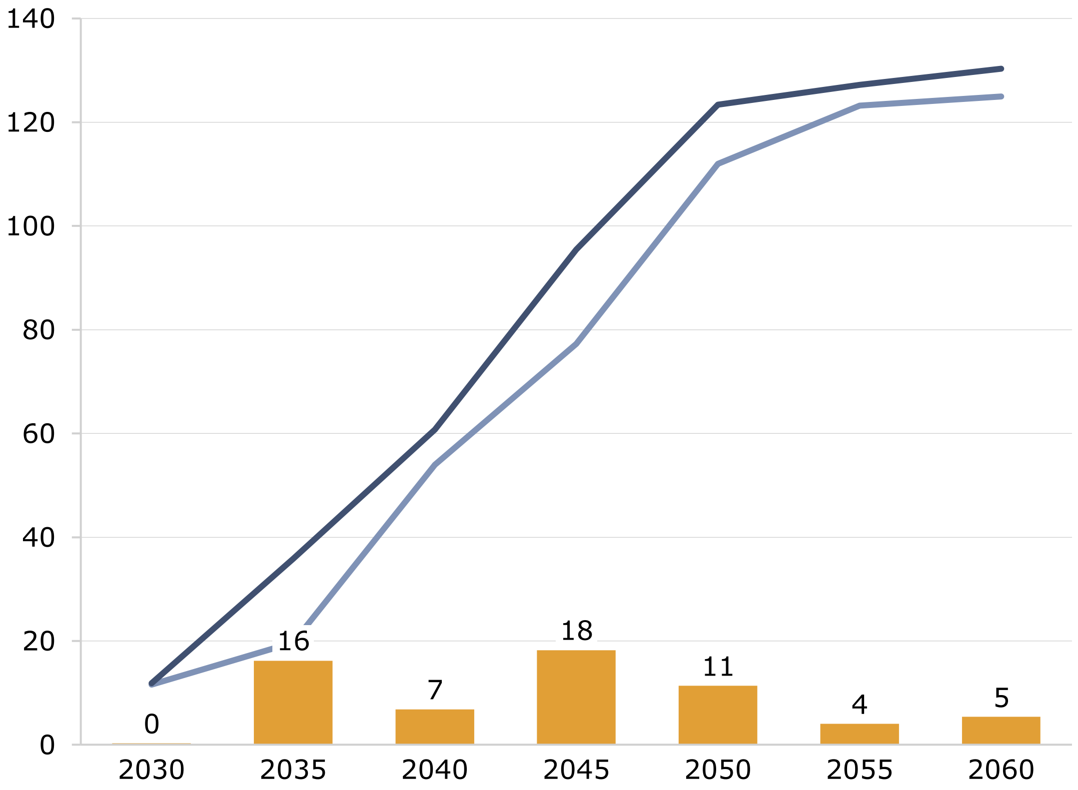

 

# Power demand is higher with a backbone as more electrolysers are built; $H_2$ demand is also higher since green $H_2$ is more competitive, so used more

**ELECTRICITY DEMAND (TWH)**



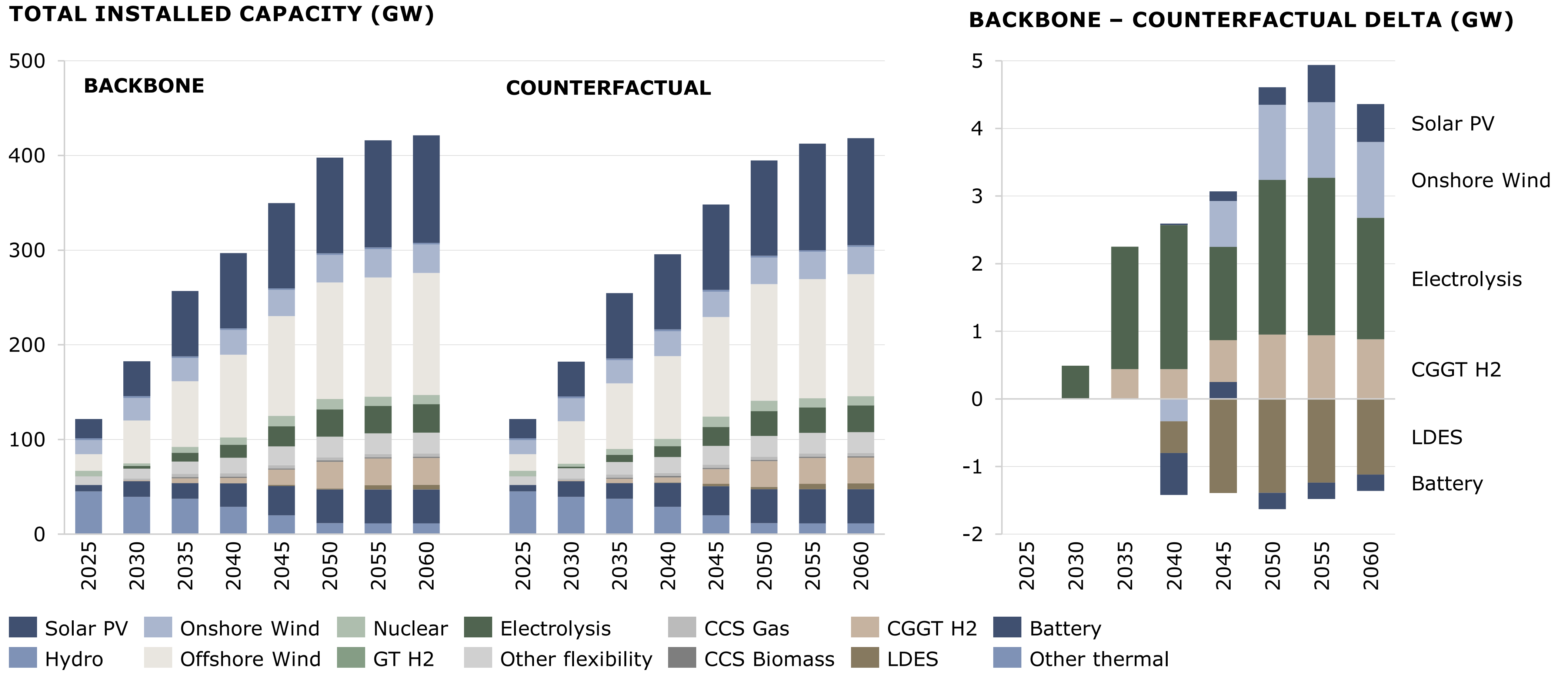

**HYDROGEN DEMAND (TWH)**




Note: we have used identical demand projections for input "base" electricity demand, and non-power hydrogen demand in the two Base cases

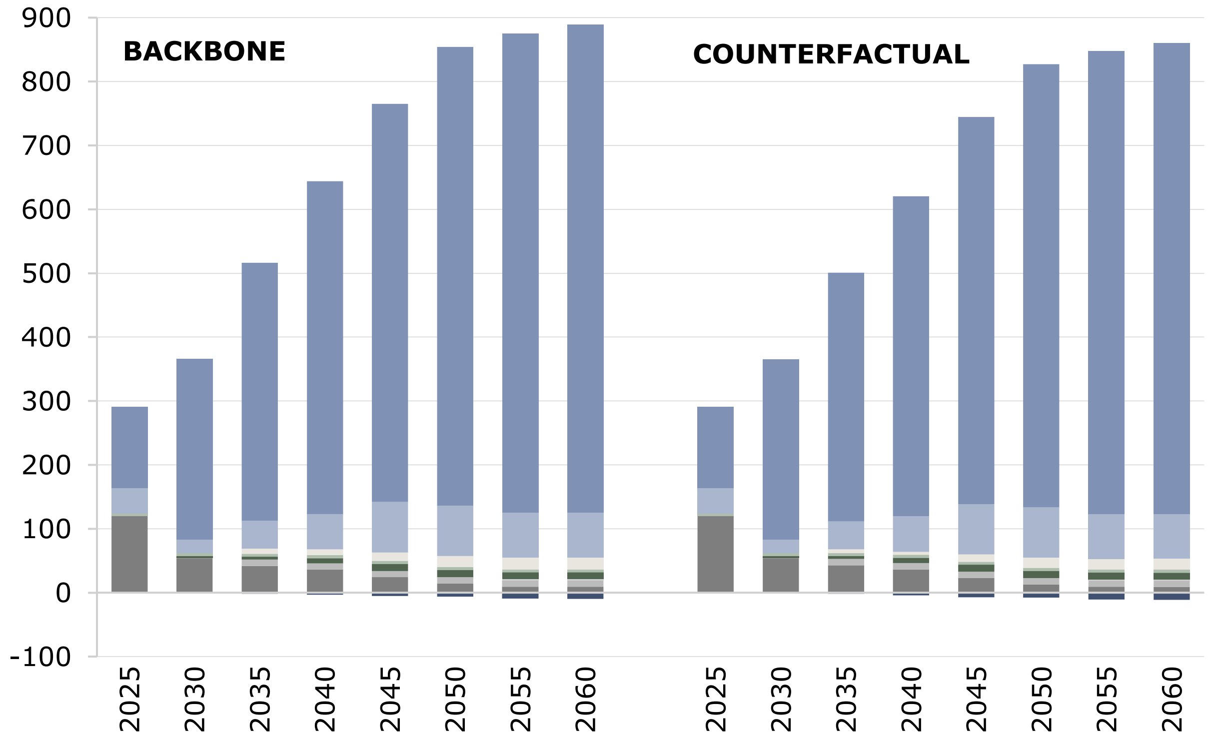
# The backbone results in a higher build of electrolysis, renewables, and CCGT $H_2$, displacing LDES and to a lesser degree batteries in the CF case



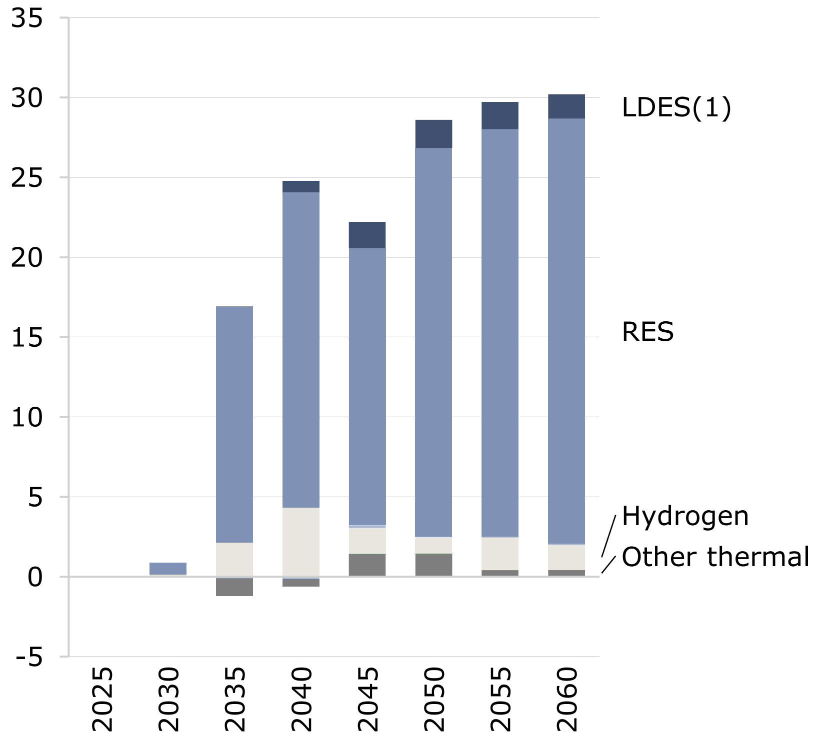

 

# The backbone increases renewable generation due to reduced curtailment and increased capacity build, as well increasing $H_2$ CCGT generation

**TOTAL POWER GENERATION (TWH)**




**BACKBONE - COUNTERFACTUAL (TWH)**

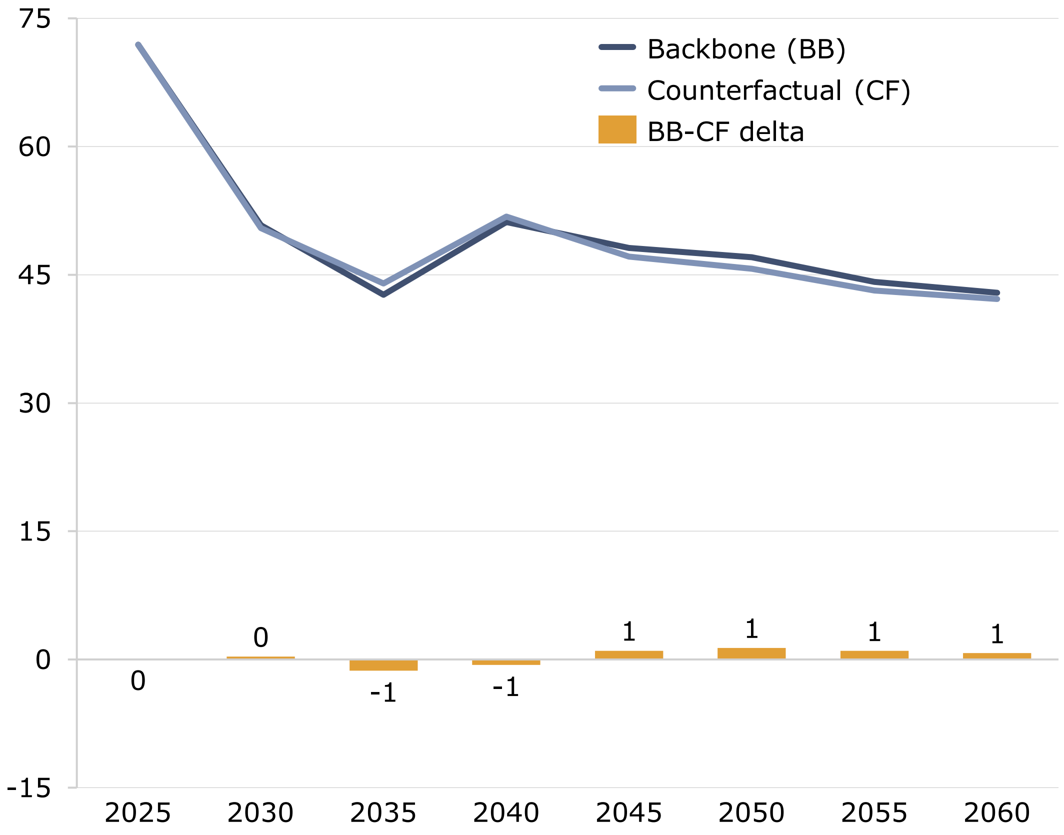



LDES RES Nuclear CCGT Hydrogen Hydro DSR CCS Waste CCS Gas CCS Biomass Other thermal

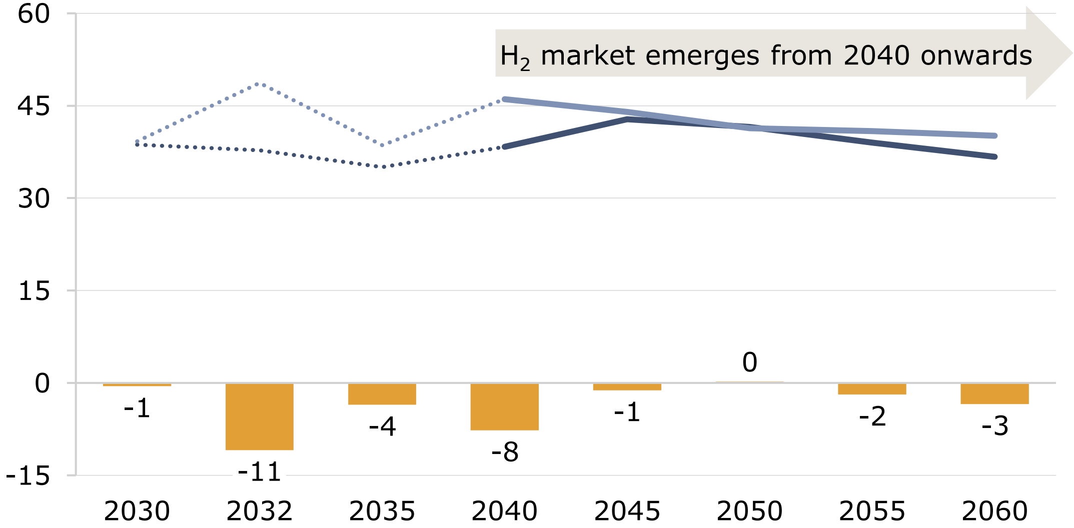
1. LDES is shown as negative generation in both the Backbone and Counterfactual cases reflecting the fact that its round trip efficiency is <100%. The difference in LDES is therefore shown as positive here because LDES is less used in the Backbone case, which has a lower overall consumption than in the Counterfactual

# Wholesale electricity prices with a backbone are similar at a national level to the Counterfactual whilst hydrogen prices are typically lower with a backbone

## DEMAND WEIGHTED NATIONAL ELECTRICITY PRICE (REAL 2023 £/MWH)




## DEMAND WEIGHTED NATIONAL HYDROGEN PRICE (REAL 2023 £/MWH)




Hydrogen price projections are an output of our BID3 co-optimisation and hydrogen modelling. Price projections for our modelling begin in 2040 in line with our assumption that it would take approximately 15 years for a commoditised market to emerge. Prices before 2040 are therefore shown as dotted lines.

Hydrogen prices include a mixture of production from blue and green (low carbon) hydrogen sources and do not represent hydrogen production of grey hydrogen



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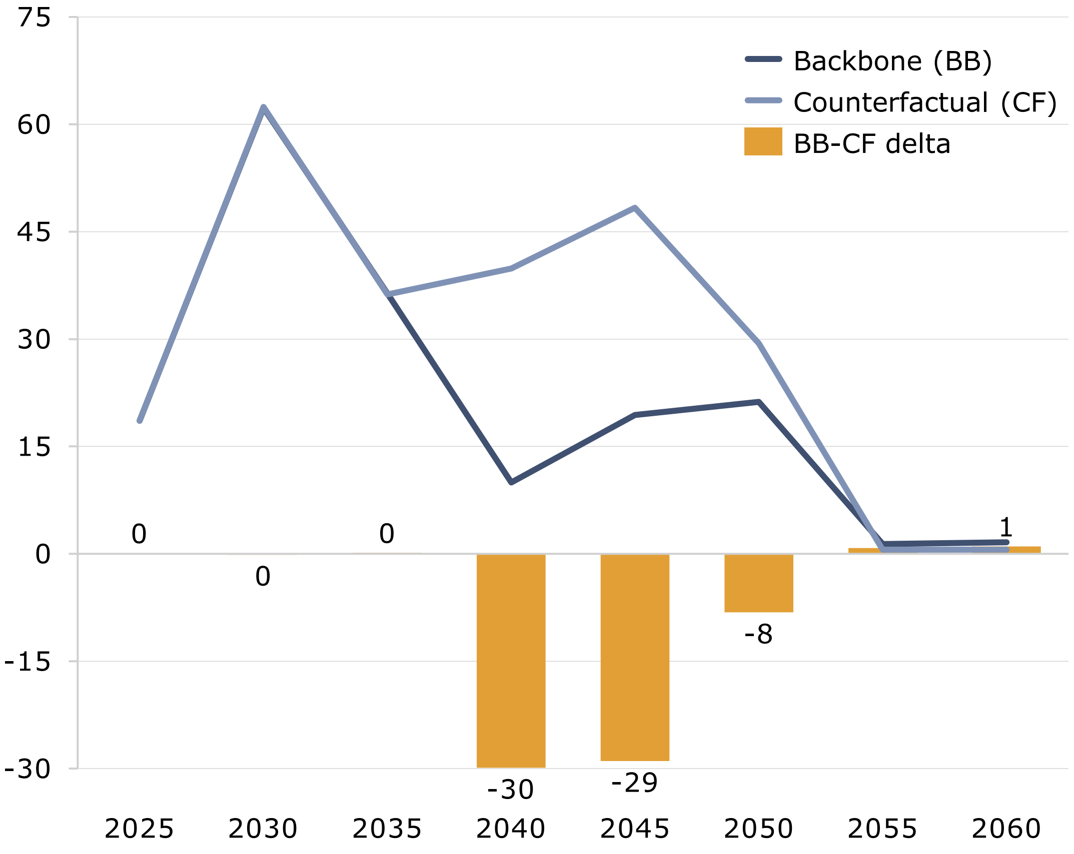
# A backbone results in a lower capacity market clearing price than the Counterfactual in the 2040s and early 2050s

**DEMAND WEIGHTED NATIONAL CLEARING PRICE (REAL 2023 £/KW)**



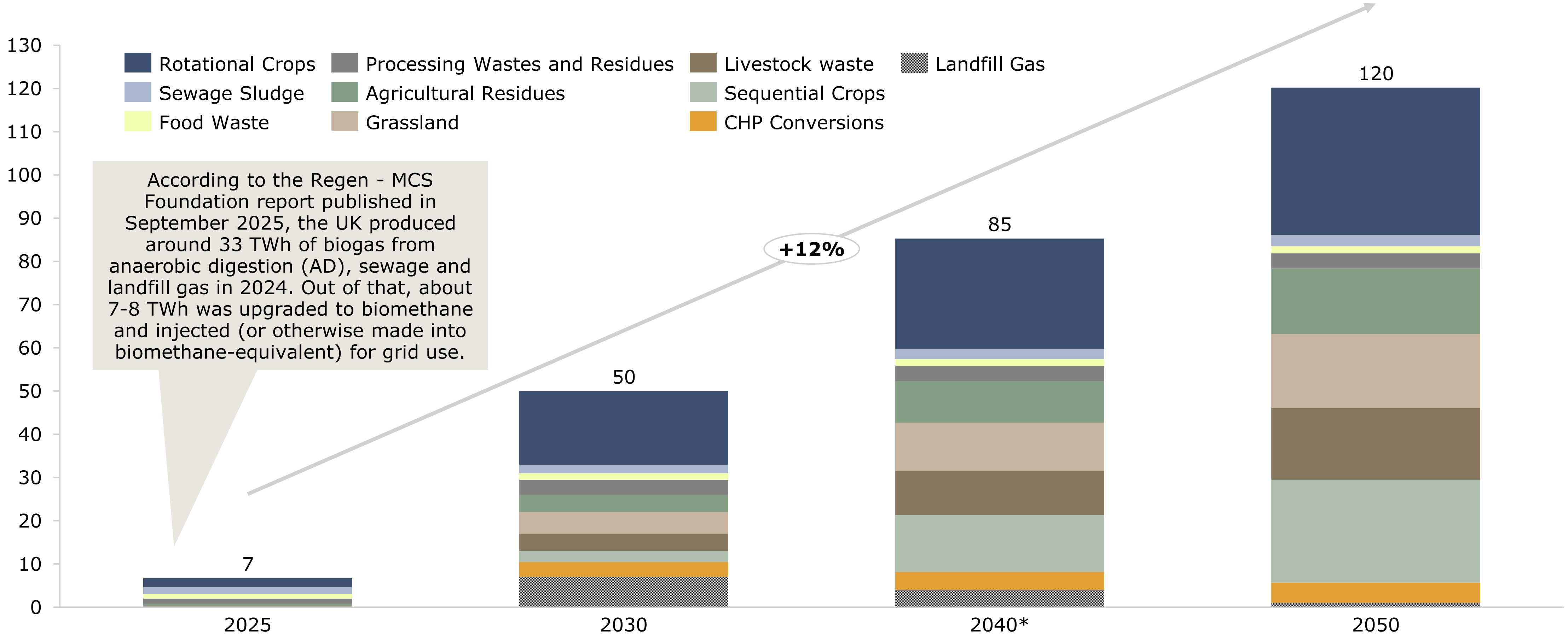

 

# Contents



# The Green Gas Task Force projects UK biomethane production as having the potential to reach 50TWh by 2030 and rising to 120TWh by 2050

## UK BIOMETHANE SUPPLY GROWTH POTENTIAL, BY FEEDSTOCK TYPE (TWH)

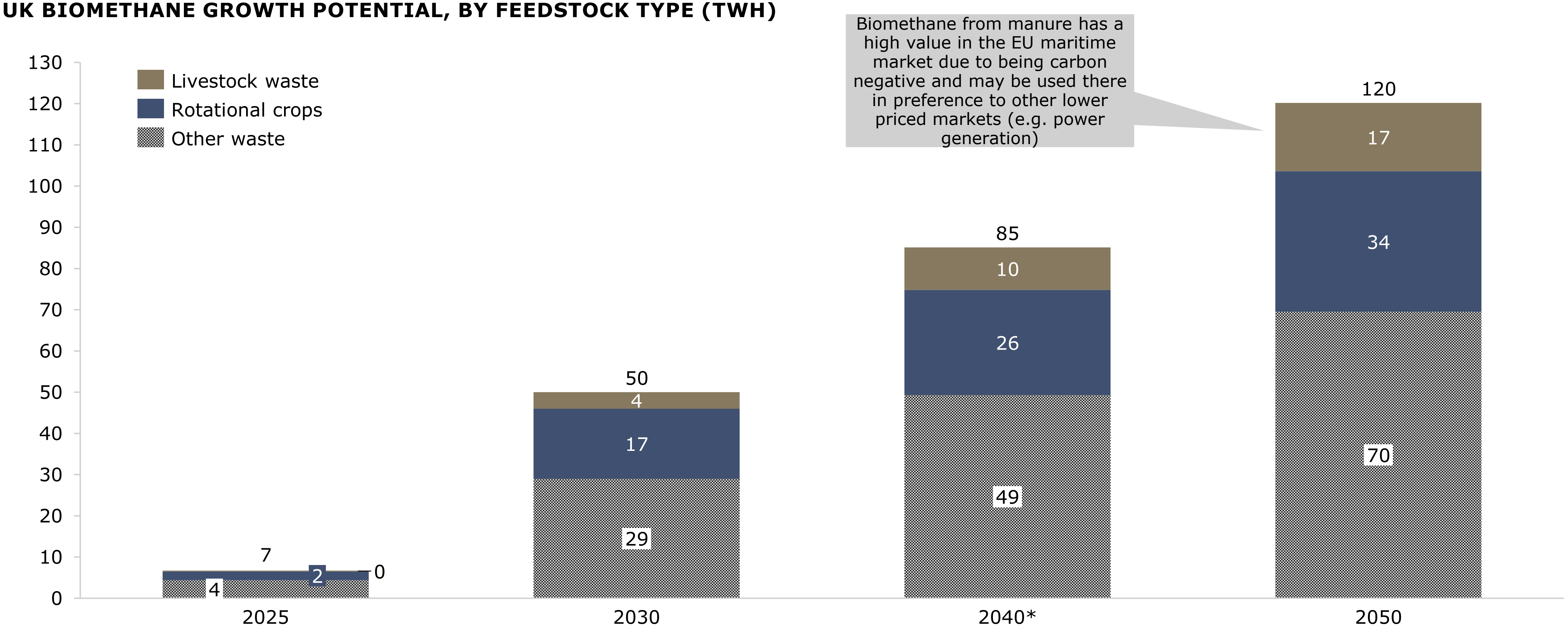



Notes: *2040 is estimated as an average of 2030 and 2050
Source: Alder BioInsights for Green Gas Task Force, MCS Foundation & Regen (2025) "Making the most of biomethane" (Version 1, September 2025).

# Grouping the biomethane by the type of feedstock from which it is produced, illustrates the dominance of biowaste as the most impactful feedstock

**UK BIOMETHANE GROWTH POTENTIAL, BY FEEDSTOCK TYPE (TWH)**

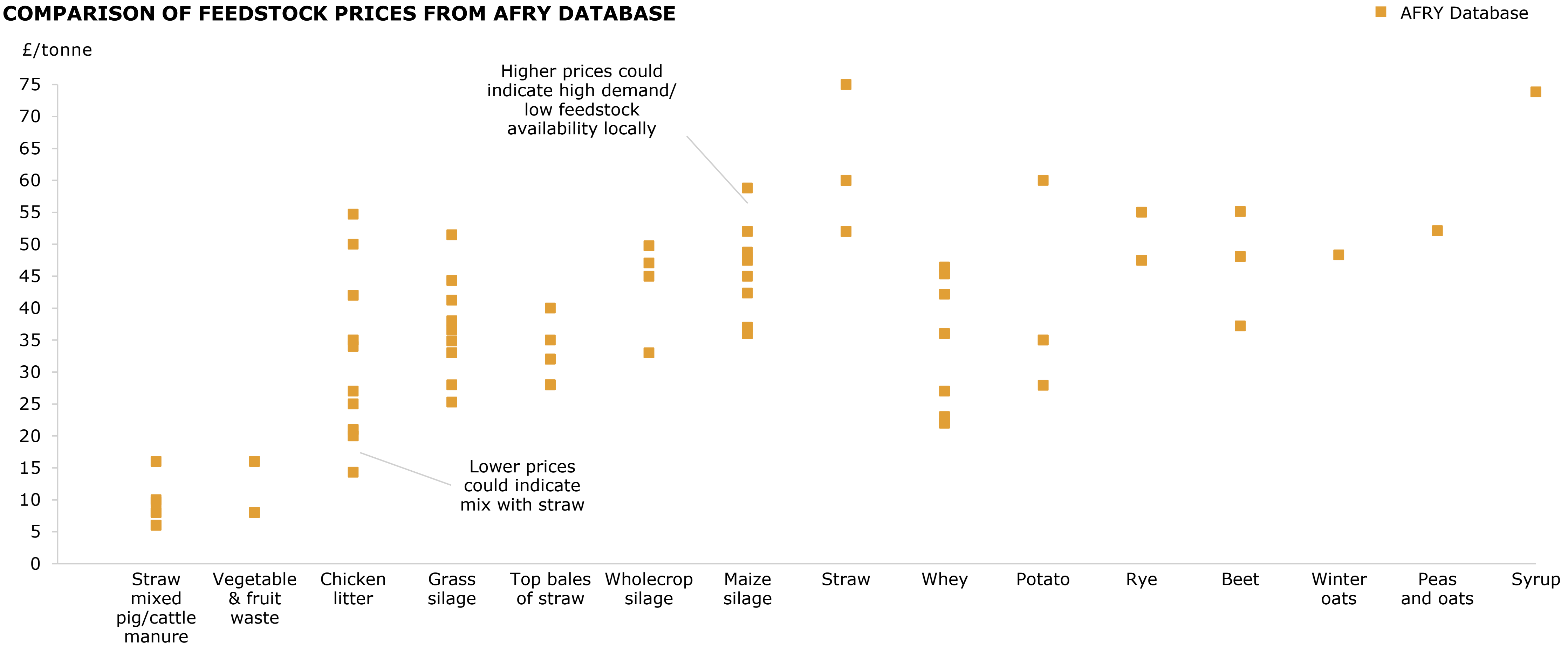



Notes: *2040 is estimated as an average of 2030 and 2050
Source: Green Gas Task Force

# AFRY maintains a UK feedstock price database covering multiple feedstock types, reflecting regional supply-demand balances and variations in quality

**COMPARISON OF FEEDSTOCK PRICES FROM AFRY DATABASE**



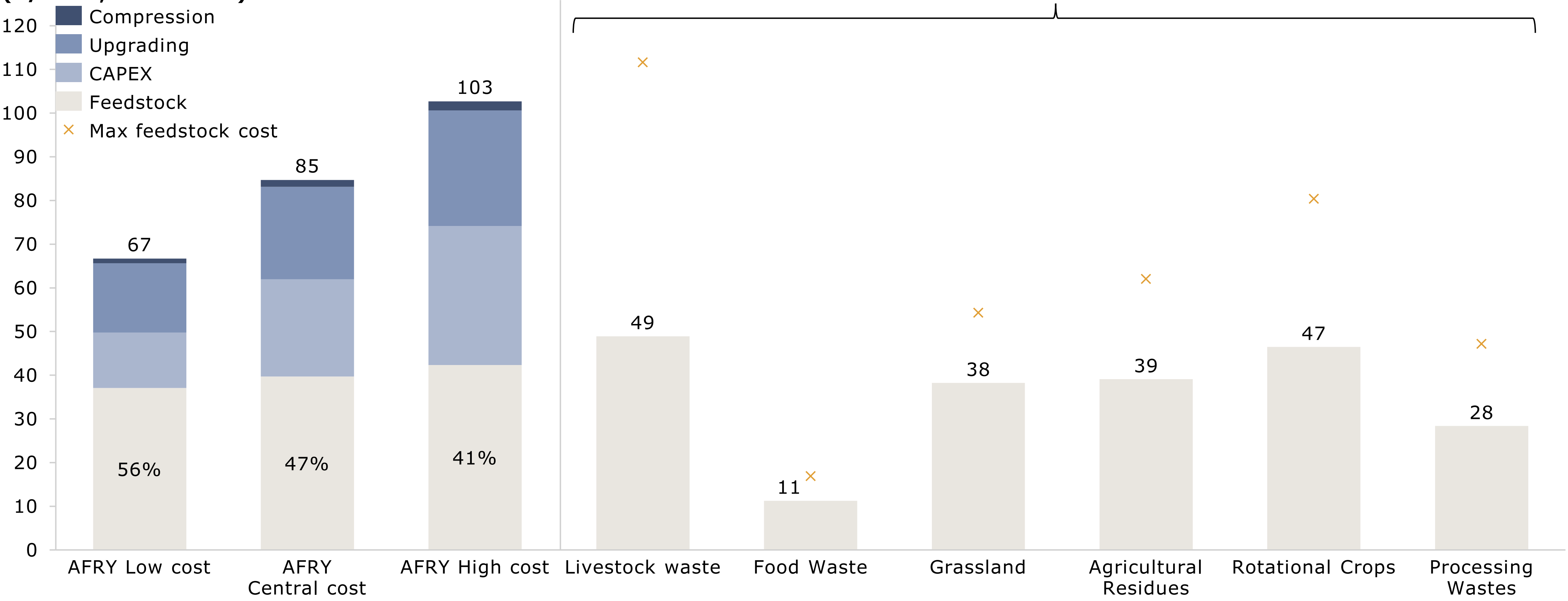

Source: AFRY Management Consulting.

# Currently, feedstock accounts for ~50% of biomethane production costs, with variation depending on the feedstock type and its methane yield

**BIOMETHANE PRODUCTION COST ESTIMATES (£/MWH, REAL 2023)***

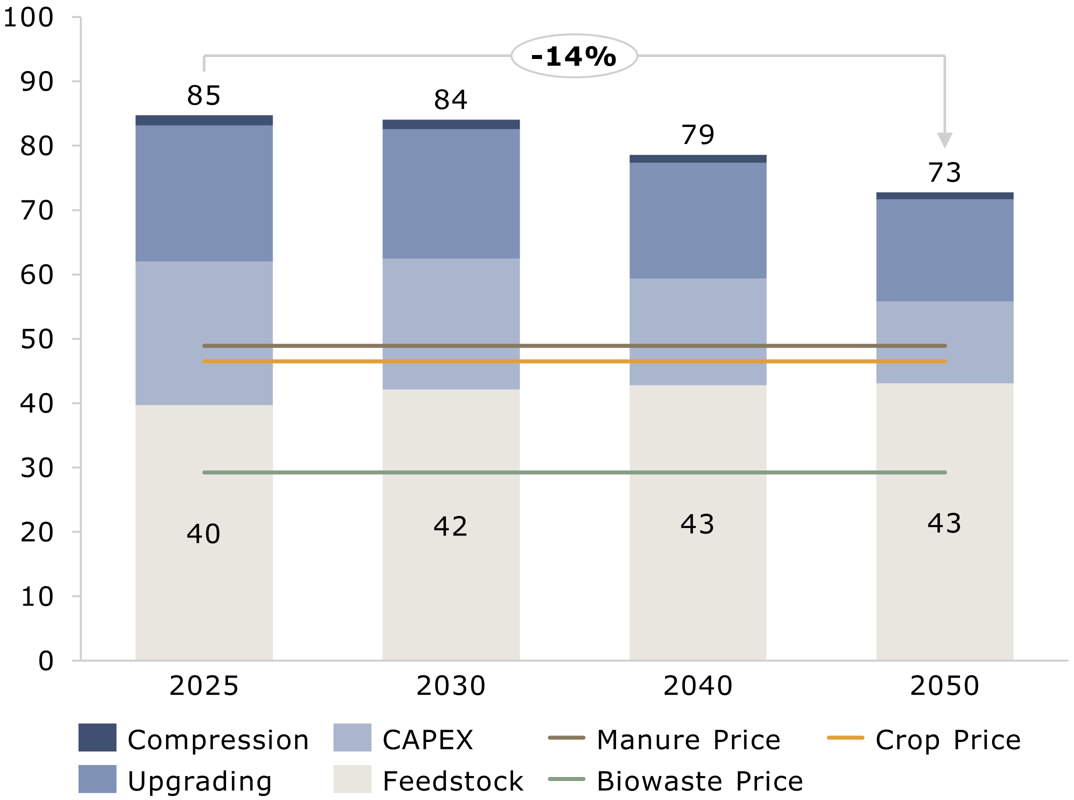
**AFRY ASSUMED FEEDSTOCK PRICES**




Notes: *AFRY develops High, Central, and Low scenarios to capture the range of plausible futures for energy markets and these are used in the AFRY market reports

# Biomethane production costs are projected to fall 14% by 2050 relative to current levels, driven by a reduction in technology and infrastructure costs

**PROJECTED UK BIOMETHANE PRODUCTION COSTS (£/MWH, REAL 2023)**

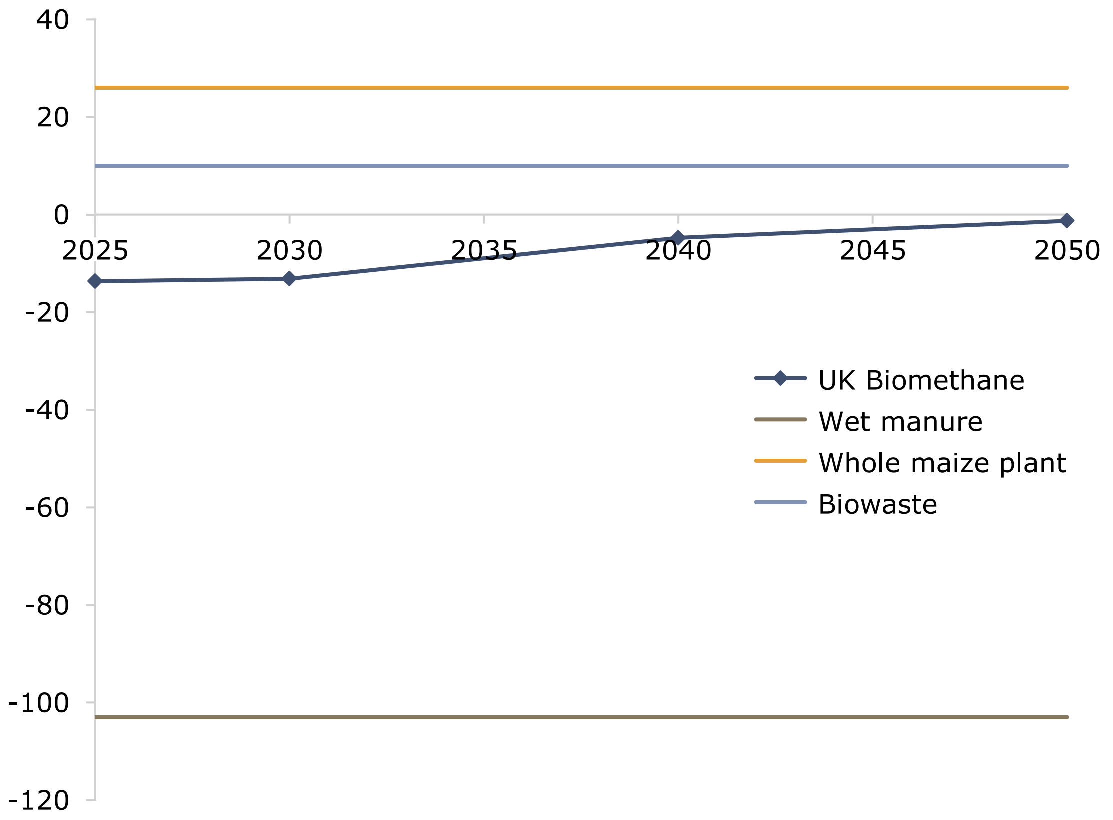



- In 2025, the biomethane production cost assumed is in line with the AFRY Central* estimate
- Out to 2050, a reduction in technology and infrastructure costs (compression, CAPEX and upgrading costs) is expected, driven by economies of scale
  - It is assumed that technology and infrastructure costs reach the AFRY Low level by 2050
- A volume-weighted average feedstock price is derived for each projected year; based on AFRY's Central feedstock price assumptions and the projected availability of each feedstock type as per the Green Gas Task Force projections
  - The average prices of the different feedstock categories are assumed to remain constant in real terms through to 2050, but the mix changes over time resulting in changes in the average feedstock price
  - The feedstock cost component is projected to increase out to 2050, driven by a growing share of higher-cost feedstock types such as livestock waste and rotational/sequential crops which partially offsets the reduction in technology and infrastructure costs
- The biomethane production cost is used in the quantification of the total system cost, with the assumption that the cost remains flat during the period 2050-2060. Values for the intermediate years are derived by linear interpolation between the modelled reference years

Note: the livestock waste price was used for sewage sludge and landfill gas. *AFRY develops High, Central, and Low scenarios to capture the range of plausible futures for energy markets and these are used in the AFRY market reports

# Biomethane production's carbon intensity is projected to remain negative through to 2050, albeit slightly increasing as the share of crops rises

## PROJECTED UK BIOMETHANE CARBON INTENSITY ($GCO_2EQ/MJ$)




Source: RED II

## GREENHOUSE GAS EMISSIONS FOR BIOMETHANE ($GCO_2EQ/MJ$)

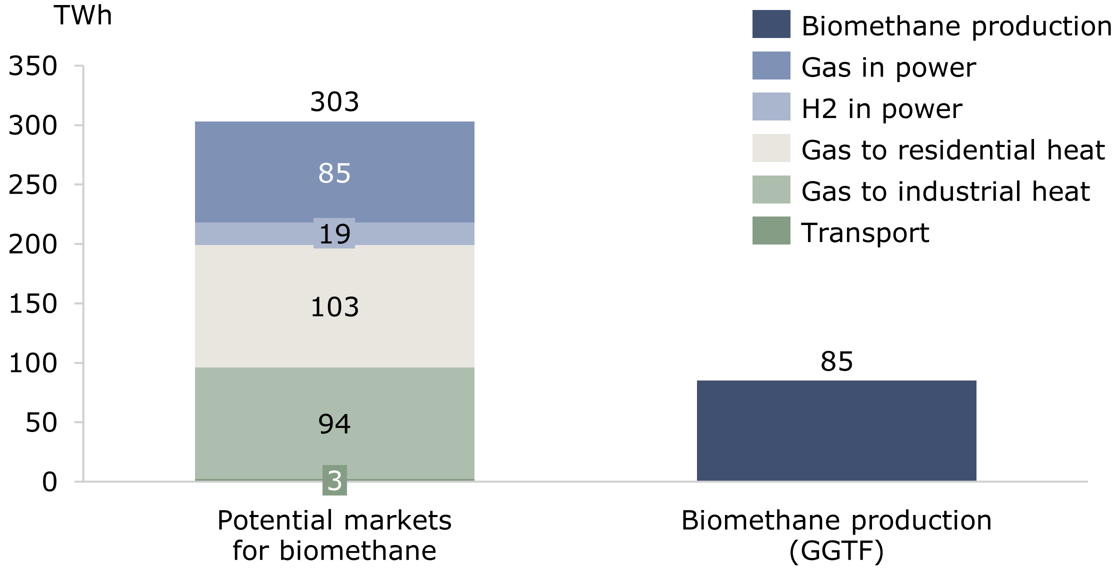
| Biomethane production system | Typical value |
|---|---|
| Wet manure | -103 |
| Maize whole plant | 26 |
| Biowaste | 10 |

- For the purposes of Sensitivity 4 and for simplicity, a carbon intensity of $0gCO_2eq/MJ$ has been assumed. However, it is noted that the actual average intensity of biomethane in the UK could be lower, subject to the share in the mix of carbon negative feedstocks.
- The carbon intensity for biomethane from different feedstocks is determined using typical values for greenhouse gas emissions for biomethane production from RED II Annex VI (see table above)
  - The wet manure typical value is assumed for livestock waste, sewage sludge and landfill gas
  - The maize whole plant typical value is assumed for rotational and sequential crops
  - The biowaste typical value is assigned to the other remaining feedstock categories with projected use for biomethane production out to 2050
- The share of feedstock with a negative, 'wet manure' typical GHG emissions value is projected to decrease out to 2050. This is driven by the rising biomethane volumes produced from sequential and rotational crops

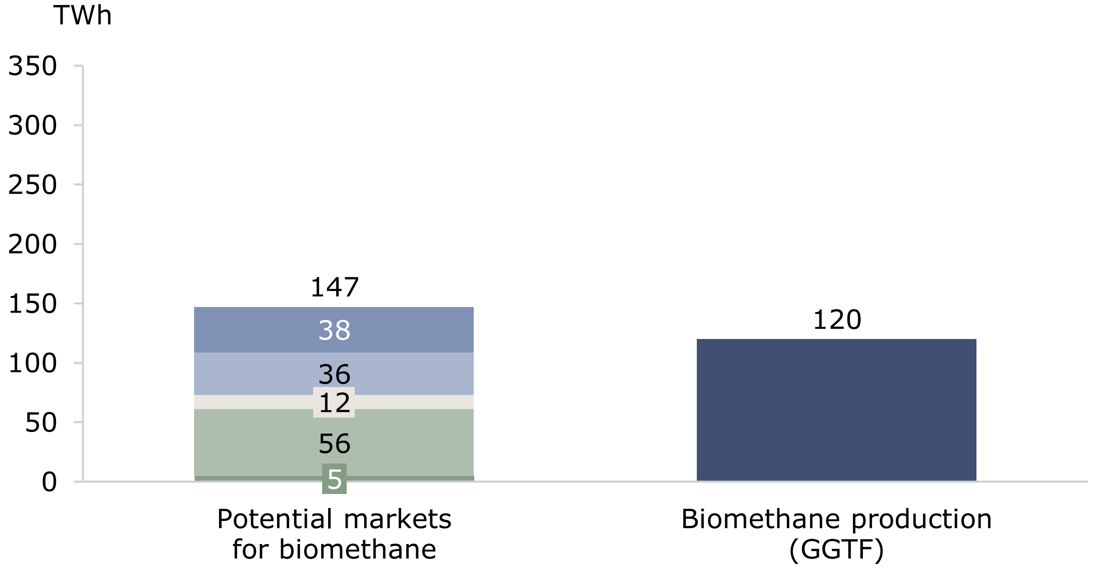
# The main assumption in the sensitivity is that biomethane is available to power generation, but there are many other competing demand sectors

**BIOMETHANE DEMAND POTENTIAL VS PRODUCTION - 2040**




- At present, 2.5TWh of gas is used in road transport, and all of this is assumed to be met by biomethane by 2040
- A caveat to the sensitivity analysis is that, by 2040, there are many competing demand sectors for biomethane. As a result, biomethane produced may be used in other sectors beyond power generation, especially where it yields higher returns.

**BIOMETHANE DEMAND POTENTIAL VS PRODUCTION - 2050**




- By 2050, demand for bioLNG for marine transport is assumed to add another 2.5TWh to the transport sector
- Overall, electrification has largely reduced potential biomethane demand in 2050
- If residential heat demand is largely met by heat pumps; then there could be enough biomethane to replace hydrogen in power

Note: Gas and hydrogen used in power is taken from the NESO Backbone scenario, heat demand is derived from AFRY's Q2 2025 Central scenario for gas demand

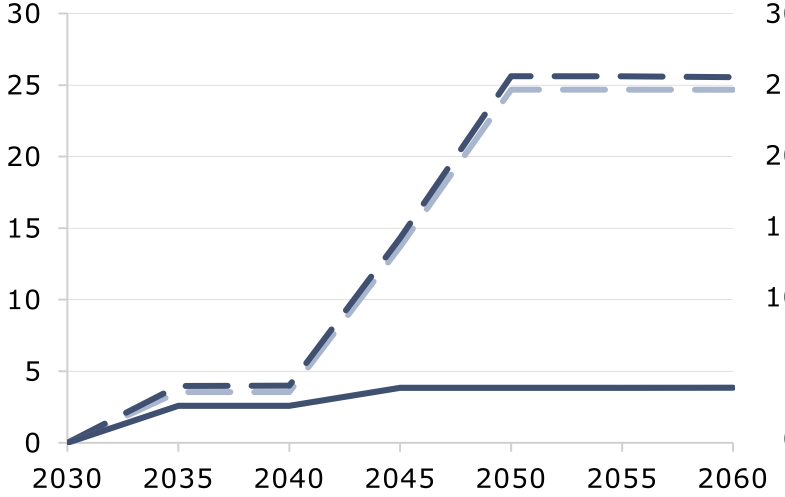
# Contents



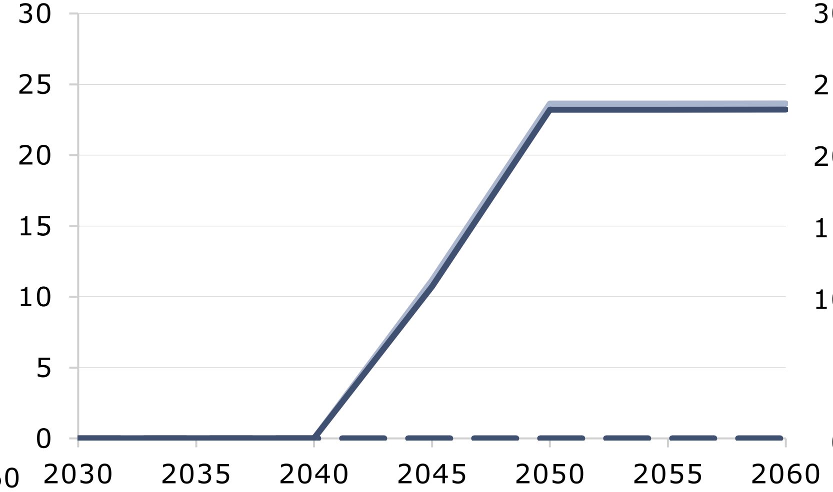
# Although biomethane becomes the dominant dispatchable build, the backbone still enables slightly more CCGT-$H_2$ relative to the CF

CF BB Solid: Sensitivity Dashed: Base case Lines overlap exactly → no difference in values

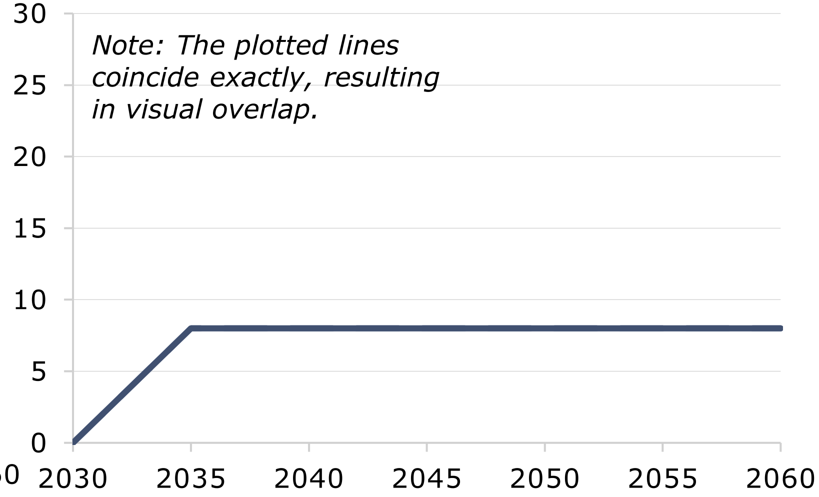
**ECONOMICALLY DRIVEN NEW CCGT $H_2$ CAPACITY (GW)**




**ECONOMICALLY DRIVEN NEW CCGT BIOMETHANE CAPACITY (GW)**




**ECONOMICALLY DRIVEN NEW UNABATED THERMAL[1] CAPACITY (GW)**




**COMMENTS**

- Charts show economic additions of CCGT-$H_2$, CCGT-biomethane, and unabated CCGTs/GTs across GB for Backbone and Counterfactual cases under the Base case and Sensitivity 5
- CCGT $H_2$ additions are retrofits in the North; unabated CCGTs/GTs are in the Midlands and South. Biomethane CCGTs are GB-wide, concentrated in the Midlands and South.
- Key points to note include:
  - **CCGT $H_2$/Biomethane:** the Backbone allows slightly more economic build of CCGT $H_2$ capacity reflecting better access to lower cost hydrogen which replaces a small amount of CCGT biomethane.
  - **CCGTs & GTs:** There is no difference in new build of unabated CCGTs and GTs between the Base case and sensitivity.

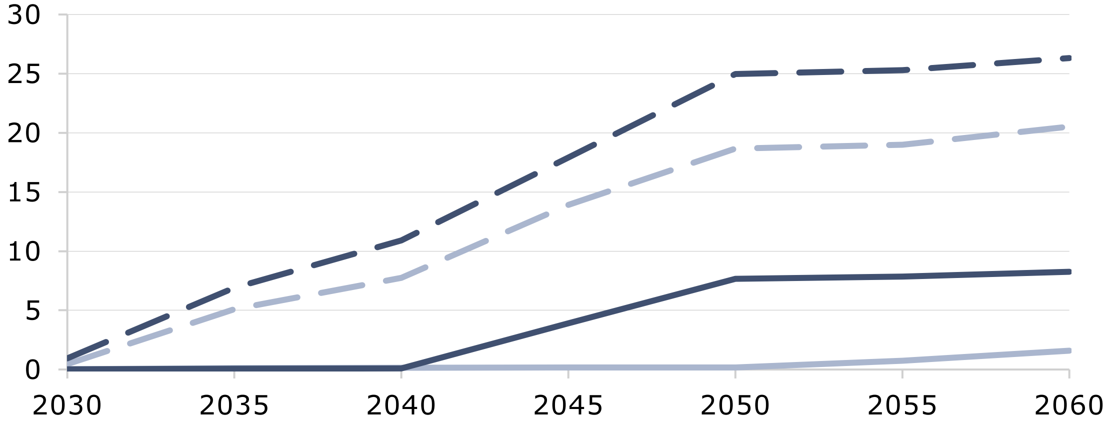
1 – Includes CCGT and OCGT technologies

# $H_2$ production capacities in the sensitivity will be more dominated by SMR-CCS technology due to high electrolyser costs and lower $H_2$ to power demand

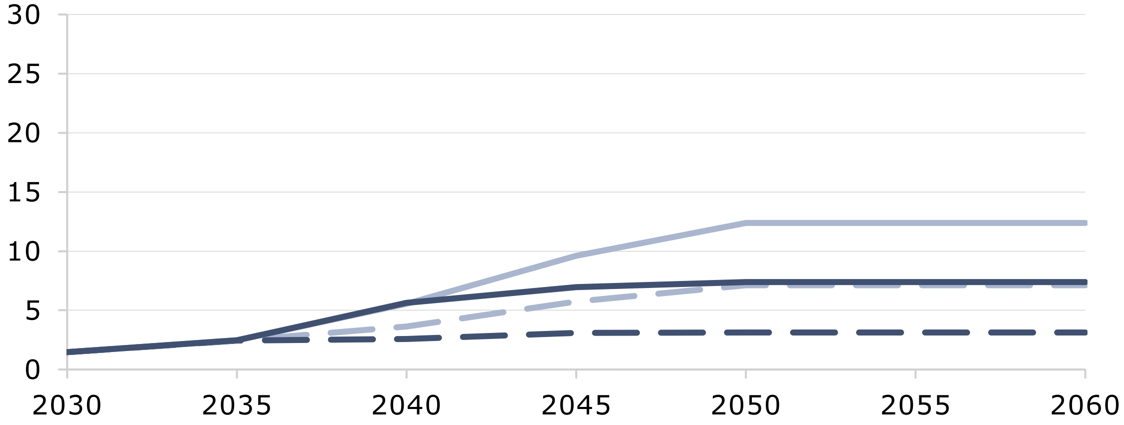
CF BB Solid: Sensitivity
Dashed: Base case

Lines overlap exactly → no difference in values

**INSTALLED CAPACITY OF ELECTROLYSERS (GW)**




**INSTALLED CAPACITY OF SMR (GW)**




**COMMENTS**

- The charts present total GB electrolyser and SMR capacities for Backbone and Counterfactual scenarios under the Base case and Sensitivity 5.
- Key points to note include:
  - **Electrolyser capacity:** Electrolyser capacity drops relative to the Base case because of high costs and reduced $H_2$-to-power demand as CCGT-$H_2$ is displaced by biomethane. With a Backbone, GB adds nearly 7 GW more electrolyser capacity long-term by enabling production in high-renewables zones and piping hydrogen to demand hubs.
  - **SMR-CCS:** In this sensitivity, SMR-CCS outcompetes electrolysers and dominates $H_2$ production. A Backbone lowers reliance on SMR-CCS by enabling lower cost electrolyser deployment and hydrogen transport, creating a more balanced production mix than in the Base case.

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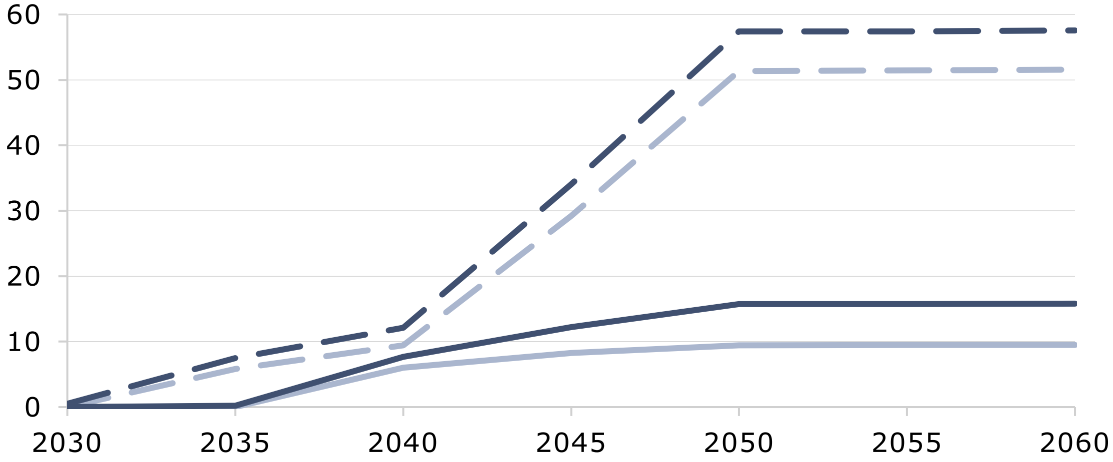
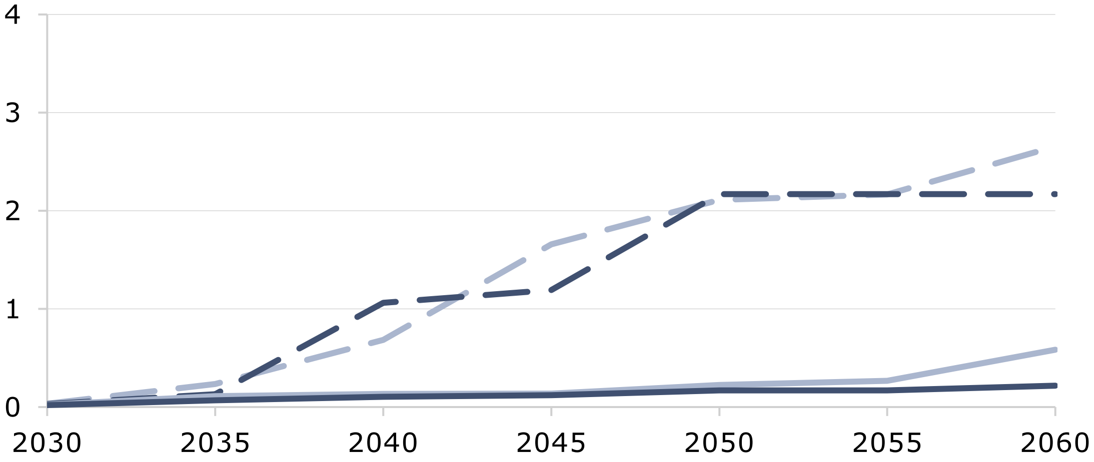
# H2 storage is significantly less in the sensitivity compared to the Base case due to lower build of electrolysers and reduction in $H_2$ to power demand

CF BB Solid: Sensitivity Dashed: Base case Lines overlap exactly → no difference in values

**ECONOMICALLY DRIVEN NEW SALT CAVERNS CAPACITY (GW)**




**ECONOMICALLY DRIVEN NEW HYDROGEN TANKS CAPACITY (GW)[1]**




**COMMENTS**

- The charts present GB hydrogen salt cavern and tank capacity additions for Backbone and Counterfactual scenarios under the Base case and Sensitivity 5.
- Key points are:
  - **Salt Caverns:** Compared with the Base case, salt cavern capacity falls sharply in both the Counterfactual and Backbone scenarios due to lower electrolyser build—driven by higher costs and reduced $H_2$-to-power demand. The Backbone enables around 6 GW more cavern capacity long-term, as caverns in the North can store hydrogen transported from Scottish zones and supply local or southern demand.
  - **Hydrogen Tanks:** similar to the salt caverns, H2 tanks are reduced in the sensitivity compared to the Base case. Adding a backbone will reduce the $H_2$ tank storage capacity even further reflecting the relative economic attractiveness of salt caverns over hydrogen tanks.

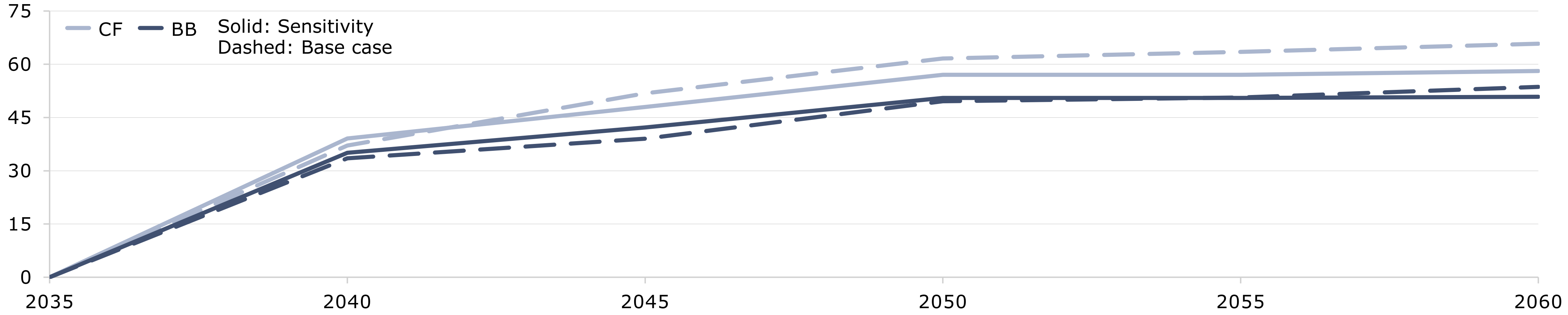
1. Note the different scale is used on the two charts shown, with far less tank capacity coming onto the system than salt cavern capacity in both cases

# Backbone impact on transmission is smaller here, driven by lower electrolyser build and more CCGT-biomethane in demand hubs

Lines overlap exactly → no difference in values

**NEW ELECTRICITY TRANSMISSION INSTALLED CAPACITY FROM 2035 ONWARDS (GW)**




**COMMENTS**

- The chart presents additional GB electricity transmission build for Backbone vs. Counterfactual under the Base case and Sensitivity 5.
- Key points include:
  - **Sensitivity impact:** Transmission build in the Counterfactual is lower in the sensitivity than in the Base case because CCGT-biomethane is built directly in demand centres
  - **Backbone impact:** By 2060, the Backbone reduces transmission build by ~7 GW relative to the Counterfactual, a much smaller reduction than in the Base case. While the Backbone enables surplus power to be converted to hydrogen and moved through the network, the impact is limited because high costs restrict electrolyser deployment.

Note: we have only allowed the model to add new electricity transmission capacity in the Central scenario cases once the ETYS 2035 planned build out has occurred. This is because we view it as unlikely that additional transmission capacity on top of the ETYS 2035 plan will occur in this timeframe because of long planning times to put transmission capacity in place

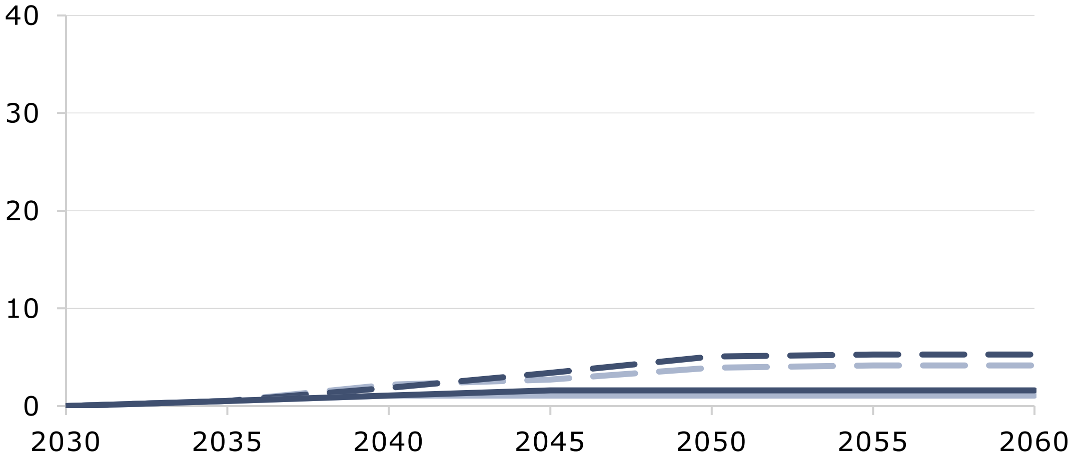
  

# RES capacity is lower in the sensitivity compared to the Base case due to the lower build of electrolysers given their higher costs

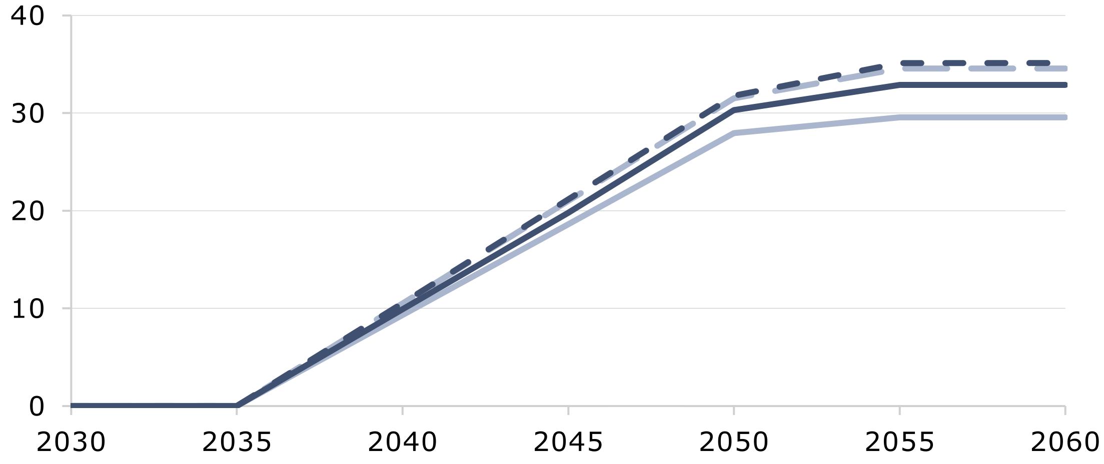
CF BB Solid: Sensitivity
Dashed: Base case

Lines overlap exactly → no difference in values

**NEW ONSHORE WIND (GW)**




**NEW SOLAR PV (GW)**




**COMMENTS**

- The charts show capacity additions of onshore wind and solar PV in GB for the Backbone and Counterfactual scenarios for the Base case and Sensitivity 5.
- Key points include:
  - **Onshore wind:** compared to the Base case, the sensitivity exhibits much less onshore wind build due to lower build of electrolysers combined with less H2 to power demand. Adding the backbone increases onshore wind capacity slightly.
  - **Solar PV:** similar to onshore wind, the sensitivity exhibits less solar PV build compared to the Base case. Adding the Backbone will increase solar PV capacity, but to a higher degree compared to the Base case, due to a more relative increase in electrolyser capacity between the Backbone and Counterfactual scenarios.



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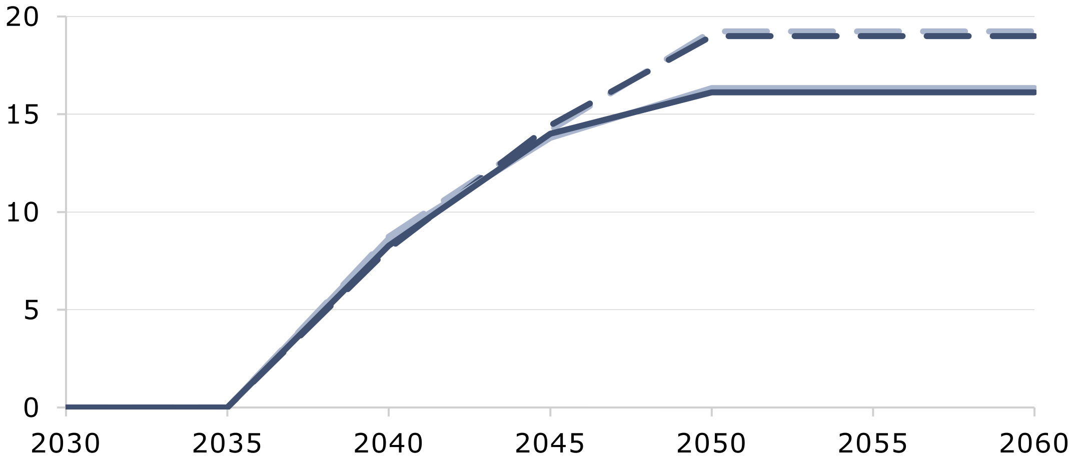
# Batteries drop with biomethane CCGTs supplying local demand; LDES grows to cover flexibility lost from fewer electrolysers

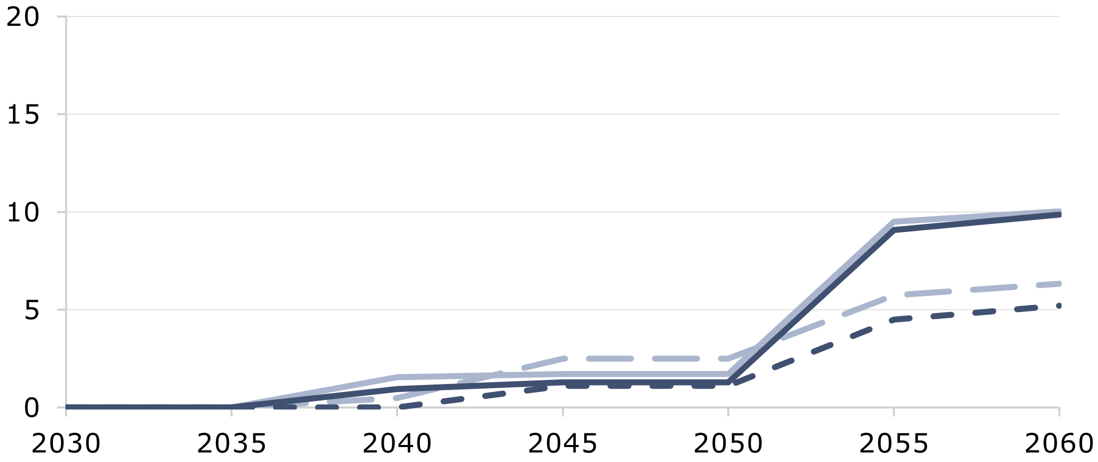
Lines overlap exactly → no difference in values

CF BB Solid: Sensitivity
Dashed: Base case

**NEW 6 HR BATTERY CAPACITY (GW)**




**NEW LDES CAPACITY (GW)**




**COMMENTS**

- The charts present GB 6-hour battery and LDES additions for Backbone and Counterfactual scenarios under the Base case and Sensitivity 5. Key points include:
  - **6 hr batteries:** Battery capacity declines relative to the Base case, as biomethane CCGTs meet demand locally. The Backbone makes only a slight difference.
  - **LDES:** Lower electrolyser build and weaker $H_2$-to-power demand increases reliance on northern LDES for long-duration wind storage. Within the sensitivity, The Backbone reduces LDES modestly compared to the CF.

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# Contents

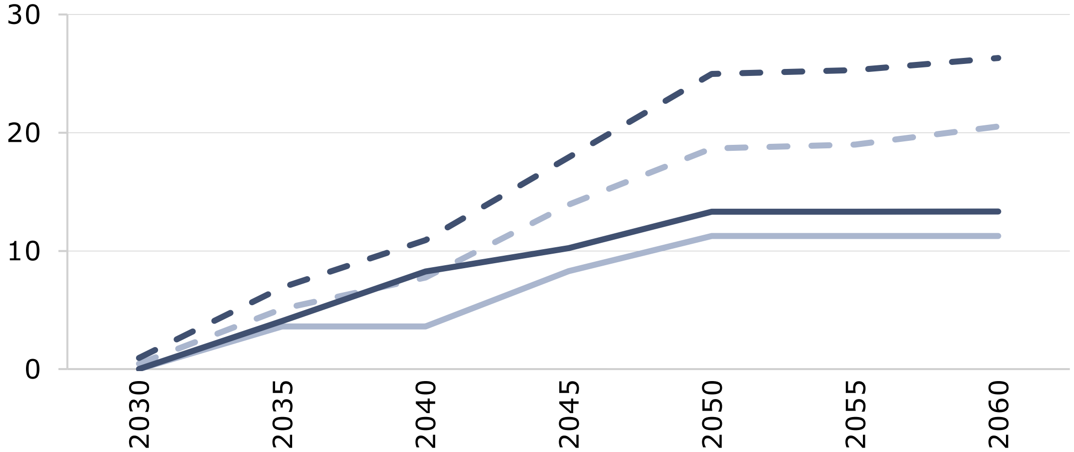


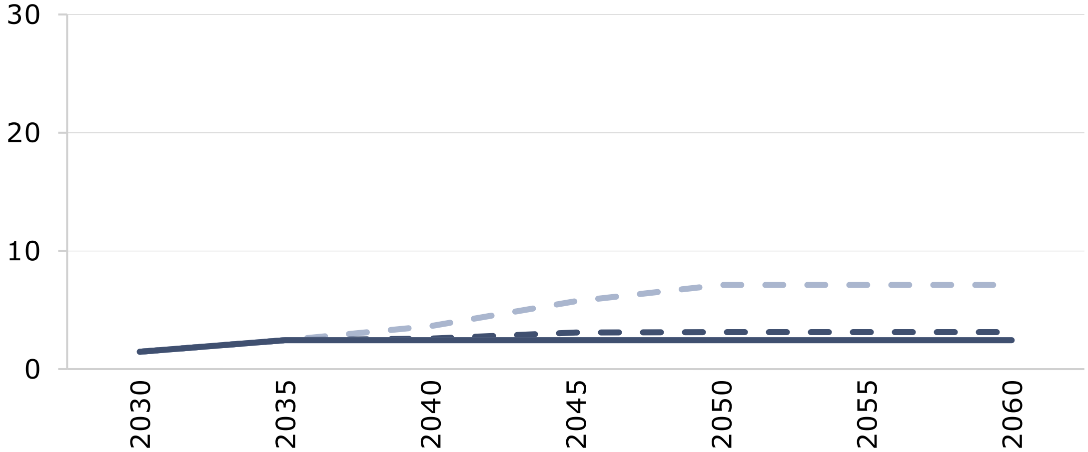
# Sensitivity 6 reduces electrolyser and SMR-CCS build-out as removal of non-power hydrogen demand sharply lowers total hydrogen needs

CF BB Solid: Sensitivity, Dashed: Base case Lines overlap exactly → no difference in values

**INSTALLED CAPACITY OF ELECTROLYSERS (GW)**




**INSTALLED CAPACITY OF SMR-CCS (GW)**




COMMENTS

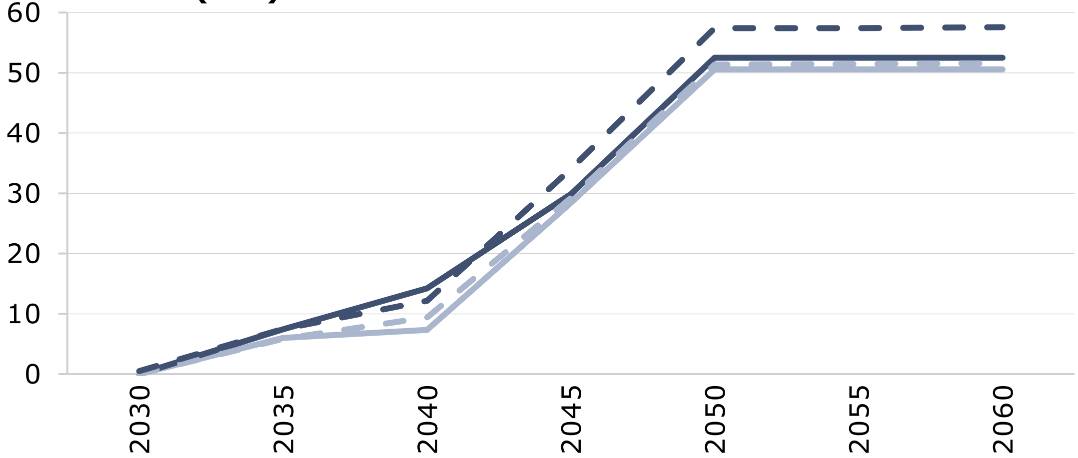
- The charts show total electrolyser and SMR-CCS capacities across GB for both the Backbone, Counterfactual and the Base.
- Key points to note include:
  - **Electrolyser capacity:** Less electrolyser capacity is added on the system under Sensitivity 6 compared to the Base case, as it is only needed to meet hydrogen demand from the power sector. The Backbone enables more electrolyser capacity overall across GB, but at a much lower level than the Base case. Electrolyser capacity increased by nearly 2GW in the long term compared to the Counterfactual in the sensitivity. This is because electrolysers are able to locate in zones with higher renewable potential, with the hydrogen produced able to travel down the pipelines to the zones with hydrogen demand.
  - **SMR-CCS:** There are no additions to the SMR-CCS capacity post-2035 under sensitivity 6 in both the Counterfactual and Backbone scenarios, as the flat hydrogen demand that SMR-CCS facilities are typically suited for is no longer present.

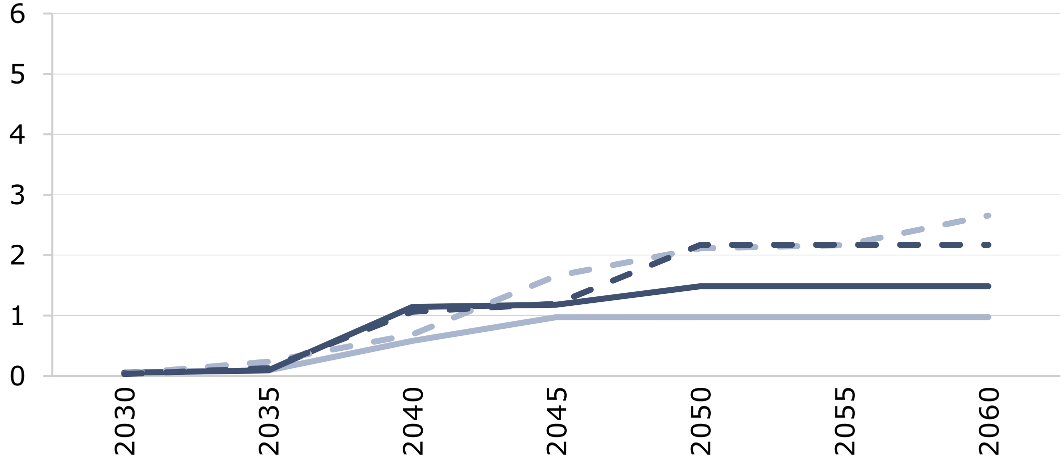
# No industrial hydrogen demand in Sensitivity 6 means that less hydrogen storage is built overall

CF BB Solid: Sensitivity, Dashed: Base case Lines overlap exactly → no difference in values

**ECONOMICALLY DRIVEN NEW GEOLOGICAL HYDROGEN STORAGE CAPACITY (GW)**




**ECONOMICALLY DRIVEN NEW HYDROGEN TANKS CAPACITY (GW)[1]**




COMMENTS

- The charts show capacity additions of hydrogen salt caverns and hydrogen tanks across Great Britain for the Backbone and Counterfactual scenarios, comparing the Base case with Sensitivity 6. Key points are:
  - **Salt Caverns:** Salt cavern storage remains significant in Sensitivity 6, but total capacity falls due to lower hydrogen demand. The backbone enables around 3 GW more cavern capacity than the Counterfactual, though this uplift is much smaller than the uplift seen in the Base case. This is because caverns in northern zones can store hydrogen transported from Scotland and supply it either locally or to regions further south.
  - **Hydrogen Tanks:** Hydrogen tanks decline overall in Sensitivity 6 compared to the Base case but rise relative to the Counterfactual when the Backbone is added, as tanks support higher export flows from South Wales and provide local flexibility.

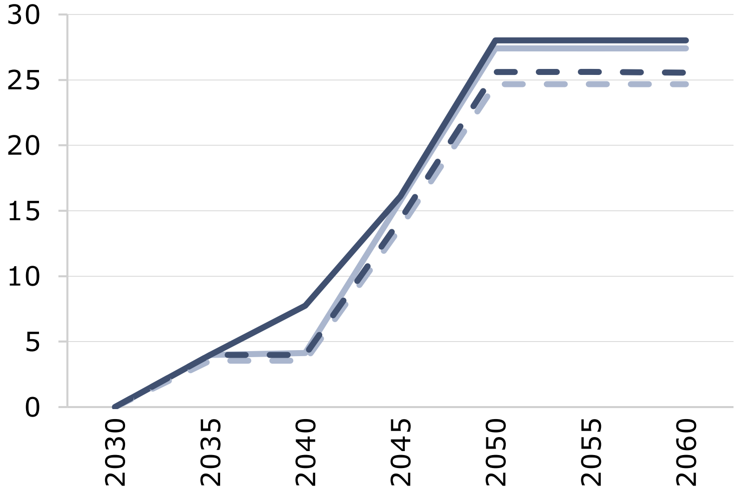
1. Note the different scale is used on the two charts shown, with far less tank capacity coming onto the system than salt cavern capacity in both cases

# Slightly more hydrogen CCGTs are being built due to cheaper hydrogen production – unabated thermal technologies remain unchanged

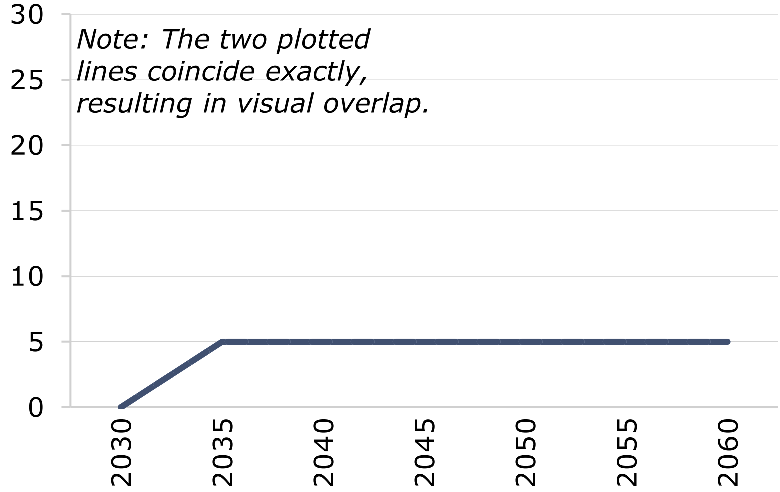
CF   BB  Solid: Sensitivity,  Dashed: Base case

Lines overlap exactly → no difference in values

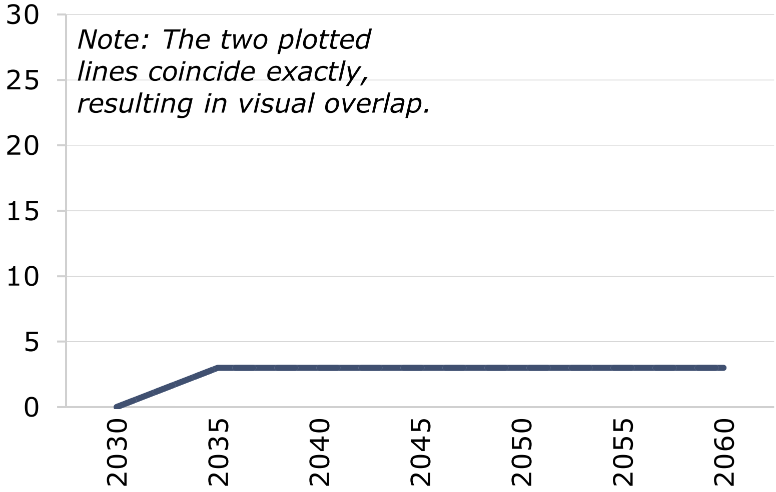
**ECONOMICALLY DRIVEN NEW CCGT $H_2$ CAPACITY (GW)**




**ECONOMICALLY DRIVEN NEW CCGT CAPACITY (GW)**




**ECONOMICALLY DRIVEN NEW GT[1] CAPACITY (GW)**




COMMENTS

- The charts show the economic capacity additions of CCGT-$H_2$, and unabated CCGTs and GTs across GB for the Backbone and Counterfactual scenarios under the Base case and Sensitivity 6. All additional CCGT-$H_2$ capacity is located in the Northern zones, while all unabated CCGT and GT build occurs in the Midlands and Southern zones.
- Key points to note include:
  - **CCGT $H_2$:** In the sensitivity, there is slightly increased build out of CCGT $H_2$ compared to the Base case replacing some of the electricity storage capacity due to cheaper $H_2$ production. The Backbone allows slightly more economic build of CCGT $H_2$ capacity reflecting better access to cheap hydrogen in other zones like Upper North and Midlands.
  - **CCGTs & GTs:** This sensitivity had no effect on unabated thermal build.

1 – GT also known as OCGT

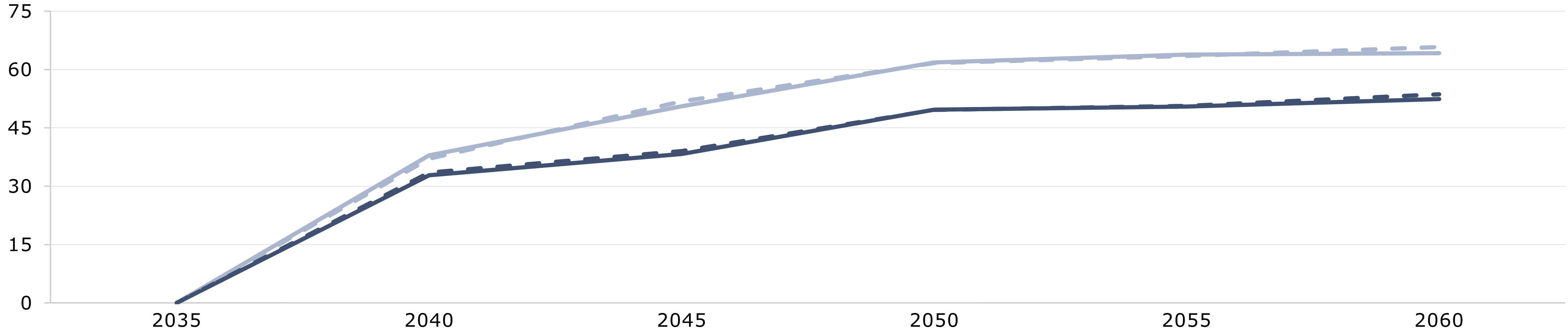
 

# Electricity transmission remained relatively unchanged in Sensitivity 6 compared to the Base case

CF BB Solid: Sensitivity, Dashed: Base case

Lines overlap exactly → no difference in values

**NEW ELECTRICITY TRANSMISSION INSTALLED CAPACITY FROM 2035 ONWARDS (GW)**




COMMENTS

- The chart above shows the additional economically driven electricity transmission network build in GB for both the Counterfactual and Backbone scenarios for the Base case and sensitivity 6.
- Key points include:
  - **Sensitivity impact:** there are only slight variations between the sensitivity and Base case.
  - **Backbone impact:** the addition of the backbone results in c.10GW less electricity transmissions build in GB by 2060 compared to the Counterfactual which is slightly less than that of the Base case as there is no longer hydrogen non-power demand. Similar to the Base case, the presence of the Backbone allows some of the surplus electricity in oversupplied zones to be converted to hydrogen using electrolysis, and then this hydrogen can be transported to where energy is needed via the Backbone. Without the pipeline, any transfer of energy between zones would have to be via the electricity transmission grid, necessitating additional build of grid.

Note: we have only allowed the model to add new electricity transmission capacity in the Central scenario cases once the ETYS 2035 planned build out has occurred. This is because we view it as unlikely that additional transmission capacity on top of the ETYS 2035 plan will occur in this timeframe because of long planning times to put transmission capacity in place

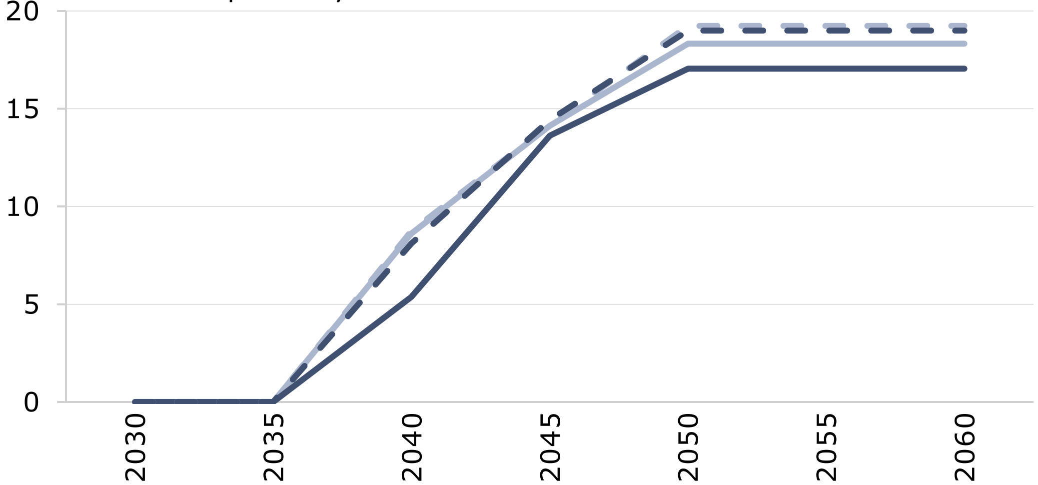
# Electricity storage is reduced in the sensitivity as they play less of a role in balancing the system as well as being replaced by CCGT $H_2$ capacity

CF BB Solid: Sensitivity, Dashed: Base case

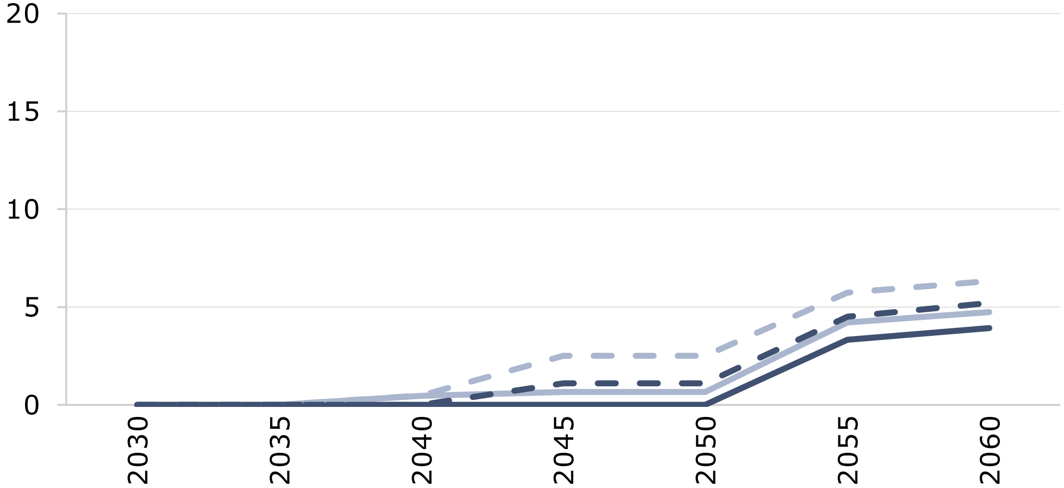
Lines overlap exactly → no difference in values

**NEW 6 HR BATTERY CAPACITY (GW)**

Lines overlap exactly → no difference vs Base case




**NEW LDES CAPACITY (GW)**




COMMENTS

- The charts show capacity additions of 6 hr batteries, and LDES in GB for the Backbone and Counterfactual scenarios for the Base case and sensitivity 6.
- Key points include:
  - **6 hr batteries:** Under sensitivity 6, fewer 6hr batteries are built overall as they play a smaller role in balancing the system due to the absence of $H_2$ demand, adding a hydrogen backbone reduces the battery capacity further as electrolysers are used to absorb excess RES. Furthermore, CCGT-$H_2$ units, which have access to cheaper hydrogen compared with the Base case, replace some of the battery capacity.
  - **LDES:** Similar to 6 hr batteries, lower LDES capacity is built under sensitivity 6. Adding the backbone reduces LDES as electrolysers are utilised more to absorb excess RES.

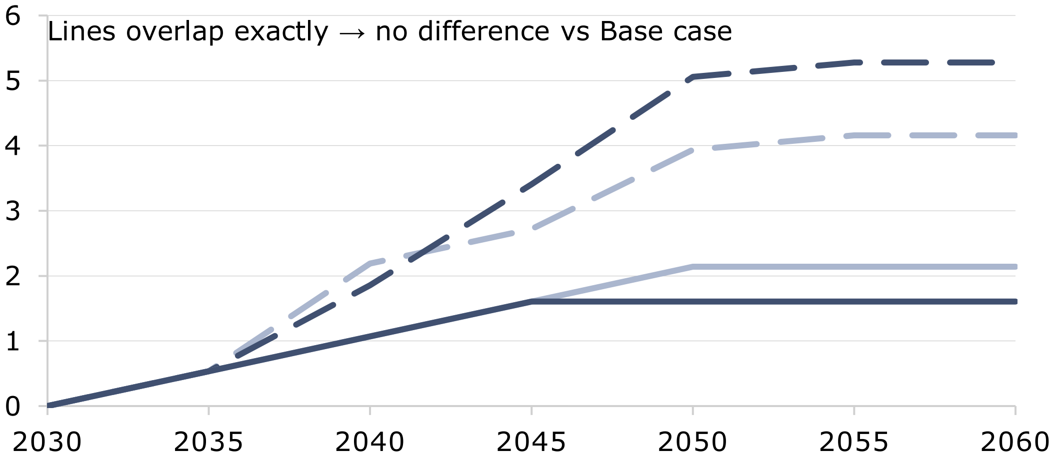
 

# RES capacity is lower in the sensitivity compared to the Base case due to less electrolyser capacity being built

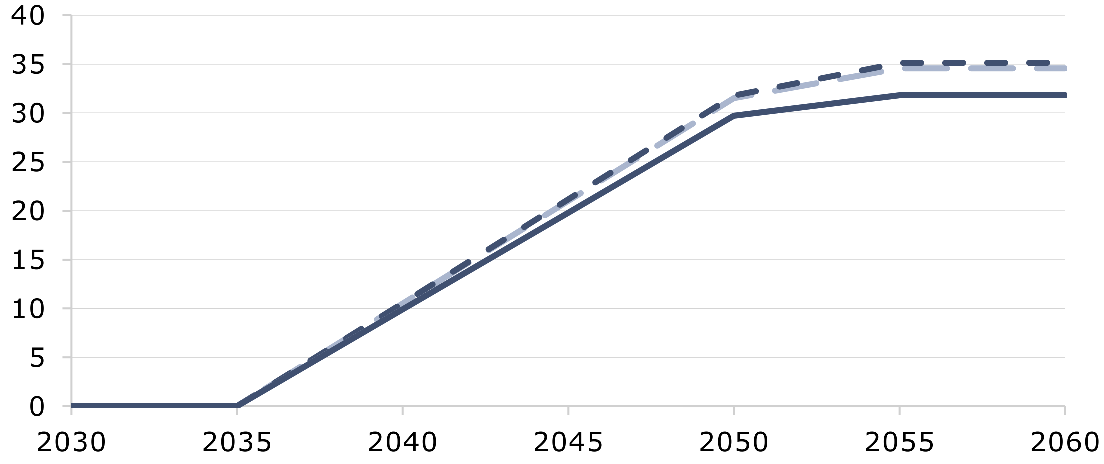
CF BB Solid: Sensitivity
Dashed: Base Scenario

Lines overlap exactly → no difference in values

**NEW ONSHORE WIND (GW)**




**NEW SOLAR PV (GW)**




COMMENTS

- The charts show capacity additions of onshore wind and solar PV in GB for the Backbone and Counterfactual scenarios for the Base case and sensitivity 6.
- Key points include:
  - **Onshore wind:** Sensitivity 6 results in less onshore wind build than the Base case, as lower electrolyser deployment increases curtailment and reduces its economic value. Adding the backbone slightly decreases onshore wind capacity—mainly in the south—because the system can instead utilise excess northern renewables for hydrogen production.
  - **Solar PV:** Similar to onshore wind, the sensitivity exhibits less solar PV build compared to the Base case. Adding the backbone does not change the solar PV capacity.

# Contents



# Glossary of terms

| Term | Definition |
|---|---|
| BB | Backbone scenario assuming a network of hydrogen pipes is built across Great Britain |
| BEIS | Former UK Government department, Department for Business, Energy and Industrial Strategy |
| BID3 | AFRY's proprietary electricity market dispatch model used to simulate and optimise power systems across multiple timeframes and geographies |
| Blue Hydrogen | Hydrogen made from natural gas using Steam Methane Reforming, with carbon emissions captured and stored. |
| CAES | Compressed Air Energy Storage |
| CAPEX | Capital Expenditure; money spent to build physical assets such as infrastructure and other equipment |
| CB7 | 7th Carbon Budget |
| CBA | Cost Benefit Analysis |
| CCC | Committee for Climate Change |
| CCGT | Combined Cycle Gas Turbine |
| CCGT $H_2$ | A version of CCGT that runs on hydrogen instead of natural gas. |
| CCS | Carbon Capture and Storage |
| CF | Counterfactual Scenario; a "what if" scenario assuming no hydrogen backbone is built |
| $CO_2$ Emissions | Carbon dioxide released into the air, contributing to climate change. |
| Curtailment | When renewable energy is available but not used due to system limits |
| Decarbonisation | Reducing carbon emissions to fight climate change. |
| DESNZ | Department for Energy Security and Net Zero |
| Discount Rate | A percentage rate used to determine the present value of future cash flows by accounting for the time value of money. |
| EfW | Energy from Waste |
| Electrolysis | A method that uses electricity to split water into hydrogen and oxygen. |
| Employment Multipliers | Numbers used to estimate how many jobs an economic activity or investment creates. |

# Glossary of terms

| Term | Definition |
|---|---|
| ETS | Emissions Trading System. It is a market-based system that sets a limit or "cap" on total greenhouse gas emissions and allows companies to buy and sell permits to emit within that cap. |
| ETYS | Electricity Ten Year Statement |
| FES | Future Energy Scenarios |
| FID | Final Investment Decision |
| Fixed OPEX | Costs that stay the same regardless of operational utilization or usage |
| FTE | Full-Time Equivalent; a way to count jobs by converting part-time work into full-time units. |
| GB | Great Britain |
| Green Hydrogen | Hydrogen made using renewable electricity (like wind or solar) |
| GGTF | Green Gas Task Force |
| GT | Gas Turbine |
| GVA | Gross Value Added |
| GWh | Gigawatt-hour |
| $H_2$ | Hydrogen |
| HGVs | Heavy Goods Vehicles |
| Hydrogen Backbone | A proposed national pipeline system to move hydrogen across Great Britain. |
| Hydrogen Storage | Facilities that hold hydrogen until required |
| Interconnectors | Infrastructure that links electricity grids between regions or countries |
| LAES | Liquid Air Energy Storage |
| LDES | Long Duration Energy Storage |
| Levelling Up | A policy goal to reduce economic gaps between regions |
| Load Factor | Ratio of a plant’s actual output to its theoretical output |
| NESO | National Energy System Operator |
| NIC | National Infrastructure Commission |
| Non-GHG Emissions | Other pollutants like NOx and SOx that affect air quality |

# Glossary of terms

| Term | Definition |
|---|---|
| NPV | Net Present Value |
| NRMM | Non-Road Mobile Machinery |
| NTS | National Transmission System |
| NZIP | Net Zero Innovation Portfolio |
| OPEX | Operating Expenditure; ongoing costs to run and maintain infrastructure |
| PtL | Power-to-Liquid |
| Salt Caverns | Underground spaces used to store hydrogen safely. |
| SMR | Steam Methane Reforming |
| Strategic Reserve | Backup energy stored for emergencies or high demand |
| Transmission Boundaries | Points where electricity moves between regions/zones |
| Variable OPEX | Costs that change depending on how much a plant is operated, hours worked, and materials consumed |
| VOWC | Variable other works costs - VOWC is used in BID3 to describe costs other than fuel and carbon incurred by generators on a per MWh basis. |
| Water Stress | Pressure on water resources, especially important for hydrogen production |
| Zonal Map | A division of Great Britain into regions for energy planning |