LONDON, KENT AND ESSEX – A DEVELOPING MARKET FOR HYDROGEN TOWARD 2050
AN ANALYSIS OF POTENTIAL DEMAND IN THE REGION
A summary of the forecast hydrogen demand for London, Kent and Essex for 2050

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A summary of the forecast Hydrogen demand for London Kent and Essex for 2050

This report aims to outline the scale of demand for hydrogen in the Region by 2050. It does not consider cost as it is intended to indicate solely the demand potential.

It is based on a combination of technology take-up forecast and sector targets.

The demand figures may well require a greater hydrogen generation capacity to respond to demand variability – particularly in heating demand for example. Here generating capacity may need to be 30 per cent higher than the total demand. This is based on the H21 work in Leeds, where delivering winter gas demand, although associated with storage, means additional capacity above demand is required. The data in this report is in effect average demand, production capacity may well have to be higher to respond to peaks.

This is a summary table of the work:

<table>
<thead>
<tr>
<th>Sector</th>
<th>Sub sector</th>
<th>Type</th>
<th>Tonnes of Hydrogen demand per annum 2050</th>
<th>Per cent of Region Demand (40 per cent domestic and commercial gas scenario)</th>
<th>Assumptions</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>ONE</td>
<td>Transport</td>
<td>Car</td>
<td>218,763</td>
<td>17.45</td>
<td>Take up driven by phase out of new internal combustion from 2035 and equal share of FCEV and BEV</td>
<td>May be high – depends on the BEV FCEV mix</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Van</td>
<td>42,343</td>
<td>3.38</td>
<td>Take up driven by phase out of new internal combustion from 2035 and equal share of FCEV and BEV</td>
<td>Who can deliver an affordable FCEV van and by when?</td>
</tr>
<tr>
<td>Sub total</td>
<td></td>
<td></td>
<td>261,106</td>
<td>20.83</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Road Transport</td>
<td></td>
<td>331,807</td>
<td>26.45</td>
<td>Very low estimate for Kent Essex and London as the majority of passenger trains are currently and likely to remain electric</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rail</td>
<td></td>
<td>500</td>
<td>0.04</td>
<td>Technology pathway for aviation decarbonisation is unclear and how the location of fuel production will be linked to consumption</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aviation</td>
<td></td>
<td></td>
<td></td>
<td>Significant potential, but technology path and significant cost challenges</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Marine</td>
<td></td>
<td></td>
<td></td>
<td>Significant potential, but technology path and significant cost challenges</td>
<td>Difficult to assess due to variety of low carbon options - but none are attractive for replacement larger replacement vessels just now</td>
</tr>
<tr>
<td></td>
<td>All Road and Rail Transport</td>
<td></td>
<td>332,107</td>
<td>26.49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TWO</td>
<td>Domestic and Commercial Gas</td>
<td>20 per cent supply into the gas grid</td>
<td>400,196</td>
<td>at 20 per cent of current gas supply</td>
<td>Demand and peak demand issues make this seem high</td>
<td></td>
</tr>
<tr>
<td>Domestic and Commercial Gas</td>
<td>40 per cent supply into the gas grid</td>
<td>800,391</td>
<td>63.84</td>
<td>at 40 per cent of current gas supply</td>
<td></td>
<td></td>
</tr>
<tr>
<td>THREE</td>
<td>Heavy industry</td>
<td></td>
<td>33,043</td>
<td>2.64</td>
<td>Assuming 20 per cent replacement of natural gas in Heavy industry users</td>
<td>Consumption based on top 50 large industrial NAEI CO2 emitters in the region</td>
</tr>
<tr>
<td>FOUR</td>
<td>Power generation</td>
<td></td>
<td>88,250</td>
<td>7.04</td>
<td>Hydrogen in Combined Cycle Gas Turbines at 20 per cent hydrogen mix</td>
<td>Hydrogen in Combined Cycle Gas Turbines at 20 per cent hydrogen mix, could be significantly higher depending on CCGT replacement strategy.</td>
</tr>
<tr>
<td>TOTALS</td>
<td></td>
<td></td>
<td>853,596</td>
<td>68.08</td>
<td>20 per cent gas</td>
<td>Represents 1.8 per cent of forecast European hydrogen demand for 2050</td>
</tr>
</tbody>
</table>

BEV Battery Electric Vehicle, FCEV Fuel Cell Electric Vehicle (hydrogen as main fuel)

Increasing demand from zero to between 800,000 and 1.25 million tonnes per annum will require a significant distribution infrastructure.
Hydrogen supply through the gas grid network has the potential to be a major demand, either as a blend or a sole product. We have looked at two scenarios, a 20 per cent blend and a forty per cent blend.

Approximately 1.25 million tonnes of demand in the Region represents close to two per cent of forecast European hydrogen demand for 2050 just over 0.2 per cent of the Hydrogen Council global forecast demand for 2050.¹

The report does not address where or how the hydrogen will be produced, however, the International Energy Agency strongly suggest port locations as being critical to future hydrogen infrastructure.²

Development of infrastructure and capacity would mean the Thames Estuary and neighbouring counties continue to develop the existing role of energy infrastructure to serve the Region and beyond.

Other locations in the UK are looking at hydrogen, but the scale and nature of demand of the Region mean it should play a leading role in developing hydrogen as a decarbonisation strategy. Other benefits include improvements in air quality and economic opportunity, as a sustainable energy solution. Facilities in the Thames and coastal ports are the logical locations to support the Region's significant demand.

Finally, it may be that the demand for hydrogen is not an issue, how to distribute it, build the required infrastructure may be the challenge. Logistics will play an important part in its potential success.

**NOTE**

This paper has used publicly available sources of information on energy consumption, energy demand from a combination of global, national and regional data.

There has been a risk that using mixed data sets has compromised some of the accuracies in the report.

However, the forecast demand equates to 1.84 per cent of European demand, 0.23 of global demand. On regional perspective hydrogen at this level would account for approximately 20 per cent of the Region’s energy requirements in 2050. (This figure excludes international aviation and marine bunkers).

This is higher figure, driven by the modelled scenario take up in transport (cars) and a 40 per cent take up in the gas grid.

*To supply this demand through renewables alone (1.25 million tonnes per annum) would it is estimated to require an eight-fold increase in peak renewable energy capacity for the region between now and 2050. This required increase in renewable does not factor in the additional demand for electricity as part of this forecast (from road transport in particular).*

(Approximated from 151,000 tonnes demand requiring peak power 2067 MW (H21 Leeds report), 1,250,000 tonnes is 8.33 times that = 17,000 MW – electricity needed 1.25 times (electrolysers efficiency), 21,250MW, current existing renewable capacity is 2.591 MW (annex 3), an 8.2 fold increase.)

¹ Hydrogen Council Demand 546 Mtpa 2050, Europe, 67.5 Mtpa 2050
1. Why hydrogen, why now?

Hydrogen as an energy medium has rapidly moved up the industrial and political agenda in 2020.

Work undertaken by the University of Kent on energy generation and consumption in Kent and Essex highlights the potential opportunity to develop hydrogen capacity on a regional scale. Significant low carbon energy medium is needed to replace petroleum (diesel and petrol) and natural gas.

Kent is well-placed in energy transformation, the county already has at least 12 different, significant, energy generation and medium to satisfy demand – hydrogen will become an additional source in 2021.

To achieve low carbon, hydrogen will have to match low or no carbon emissions ambition to user demand, deliver on cost and technical profiling.

This report will look at the regional demand opportunity for hydrogen in Kent, Essex and London.

So, why hydrogen now?

(a) The realisation of the challenge of achieving sector, national and global GHG emissions targets, the need for more significant sources of very low or no-carbon energy

Including both national and international emissions (the latter from the consumption of international marine and aircraft bunkers in the UK), overall in 2018 the UK emitted 409.8 MtCO2e, down from 619.1 MtCO2e in 1990, a reduction of 33.81 per cent or 209.3 MtCO2e.

A significant proportion of this reduction has been achieved by the replacement of coal-fired power generation with gas or renewables, industry mix and efficiency. Gas-powered generating facilities emit 50 per cent of the CO2 of their coal powered equivalents.

CO2 emissions reductions from transport though have been minimal, so now transport (including international bunkers) accounts for over 40 per cent of total UK-based CO2 emissions, as opposed to 24 per cent from power generation. This is almost the exact reverse of the situation in 1990.

NOTE: These emissions do not include CO2 emissions embedded in products consumed in the UK, netted off from products exported.

Source: Final UK greenhouse gas emissions national statistics 1990-2018, BEIS, detailed in Annex 1
(b) A significant source of energy consumption is currently met through gas and gasoline (petrol and diesel)

Regional data set for energy consumption for London, Kent and Essex (the Region) shows that 72.7 per cent of energy consumed is currently supplied directly through gas and gasoline (petrol and diesel). This is primarily for transport, commercial and industrial heating plus energy and low level power generation. This per cent excludes some power station and large industrial users – likely to be gas consumers. (This is due to commercial sensitivity of this data)

Electricity accounts for 25.45 per cent of energy consumed. Renewables share of this mix is likely to be close to 50 per cent of demand in the Region – dependent on weather variability and use of UK-Europe in the Region interceptors. It is also noted that three energy interceptors are a significant supplier of electricity to Kent.

This consumption data demonstrates the challenge of replacing gas and gasoline as energy medium, the need to increase both the supply of electricity and provide a low or no carbon alternative to Natural Gas.

Source: Sub-national total final energy consumption in the United Kingdom (2017) – detailed by local and unitary authority Annex 2

(c) An emerging and active debate of the value of blue hydrogen, generated from other forms carbon energy with associated capture and storage as well as green hydrogen, direct from renewables – research and innovation in hydrogen technology is increasing

Differences in opinion exist on a strategy for generating hydrogen, one that has both economic and environmental standpoints.

Hydrogen is not a fuel in its own right – it requires manufacture or is a bi-product from industrial processes and other fuels – to create carbon-free hydrogen its manufacture needs to be associated with:

- Renewable energy
- No carbon sources (such as nuclear)
- Gas with associated carbon offset and or capture and storage

At the point of use hydrogen (if used as a sole fuel) does not emit CO2, nor other emissions such as particulates or nitrous oxides. It is a very flexible fuel medium that can in some cases replace natural gas without modification. For example up to 20 per cent hydrogen in the gas network, as exemplified in the UK at Keele University.

Currently, an active global debate focuses on the opportunity to use blue hydrogen (manufactured from Liquid Natural Gas, with associated carbon offset or capture and storage) as a route to hydrogen scale up production and infrastructure and drive cost parity

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2 Based on a calculation of renewable energy generation capacity in Kent, Essex and London, Annex 3
(with current fossil based fuels). This is seen by some as a potential transition strategy, or complimentary strategy to green hydrogen from renewables. Other sees this route as energy inefficient and prolonging the life of carbon-based fuels.

This discussion is starting research into the cost of developing a long term hydrogen economy and how (whether through blue or green or both) to make hydrogen competitive cost wise to petroleum and gas.

The price of hydrogen and hydrogen fuel cells are coming down (but so are batteries at about the same rate), our transport demand piece will demonstrate this.

**Investment decisions for 2050 low carbon technology are long term and need investor confidence – long term confidence in fuels is needed to support critical investment**

Investment in energy technology and infrastructure is long term and given the scale of the challenge, to deliver zero carbon by 2050, that investment planning needs to be started now.

Irrespective of technologies the global investment demand is as follows:

*In the UK, for example, the Committee on Climate Change estimates that investment in greening the energy sector needs to double from an average of £10bn a year to £20bn annually, if it is to reach net zero emissions by 2050. Globally, an additional $1.1trn is needed annually between now and 2040 to meet the International Energy Agency’s green energy target.*

Imperial College London Business School goes on to suggest that confidence in low carbon technology in the investment community needs to be increased, low carbon needs to be seen as a firm, solid investment.

**Summary**

To address and overcome these challenges we aim to demonstrate the potential demand for hydrogen in the London, Kent and Essex Region – ‘Thames Estuary plus’ – the Region.

This is a location that has previously housed significant carbon, petrochemical and coal generated energy capacity and facilities. One that has played a vital role in transition to a gas-based power generation and energy stream as well as being a significant region in the renewable energy landscape. One that is now seeking research innovation and investment toward transition to hydrogen.

We have taken the view that demonstrating demand opportunity is a sound approach to investment. Demand demonstration offers scale up and certainly that can go beyond demonstration projects, one that will pull through research and innovation to upscale and commercialisation.
2. Global demand for hydrogen.

A number of forecasts exist into the global demand for hydrogen up to 2050, and they vary considerably in outlook.

Deloitte, based in Australia, reporting in November 2019\textsuperscript{vi}, developed four potential global demand scenarios for hydrogen in 2050.

*The global demand for hydrogen differs significantly across all four (of our) scenarios, with demand ranging from a high of 304 Mtpa of hydrogen by 2050 in the Energy of the Future scenario to just over 90 Mtpa by 2050 in the Electric Breakthrough scenario.\textsuperscript{vii}*

Current demand for hydrogen is estimated as 70 Mtpa, of this more than 96 per cent of hydrogen is used in industrial process\textsuperscript{viii}, often produced as a by-product of that process. Therefore hydrogen currently used as a fuel outside of integrated industry is most likely around 3.0 Mtpa, global demand per annum.

In terms of high forecast, the Hydrogen Council (made up of a consortium of Hydrogen technology followers) estimates the global demand for hydrogen in 2050 to be 546 Mtpa\textsuperscript{ix}. This would represent 18 per cent of global energy demand.\textsuperscript{x}

In contrast, IRENA, International Renewable Energy Agency, forecasts incremental demand for hydrogen (beyond industrial integrated) at 56 Mtpa\textsuperscript{xii} for 2050.

The recent ‘A hydrogen strategy for a climate-neutral Europe.’, July 2020, the European Commission outlines the strategy with an ambition to deliver the share of hydrogen in Europe’s energy mix is projected from the current less than 2 per cent to 13-14 per cent by 2050. Slightly lower than the Hydrogen Council ambition, but significantly higher than others.

The main reason for this difference is the role of electricity as a source of energy globally. IRENA’s perspective; it is most effective for renewable and no carbon energy to be used directly as electric power – across a range of energy applications, significantly increasing the share of electricity as an energy medium.

Converting renewable energy into hydrogen does create energy losses. The efficiency of electrolysis is determined by the amount of electricity used to produce an amount of hydrogen. Depending on the method used, the efficiency of water electrolyser is currently in the Region of 60 to 80 per cent (based on the calorific value).\textsuperscript{xii}

The Hydrogen Council’s perspective is to see the opportunity for significant volumes of hydrogen, from both renewable and blue hydrogen to be used an energy medium across a wide range of applications with hydrogen providing up to a 40 per cent share in some sectors.

Neither promotes technology exclusivity and it is generally accepted that all fuel types and energy media will be needed to achieve carbon reduction ambitions.

The development of battery technology for use in transport and as a storage medium, in terms of capacity, volume, weight and cost, is likely to be critical in the development of these scenarios. So too will the ability of conventional gas users in industry, commercial and domestic willingness and ability to transfer to electricity or use alternative gaseous fuel (all or part hydrogen).\textsuperscript{3}

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\textsuperscript{3} Synthetic or manufactured liquid fuels will also have a role in certain applications, such as aviation where
In summary, this means hydrogen is unlikely to be adopted as a replacement fuel across all consumption scenarios to the same degree at the same pace or rate. Depending on technical need (is electricity a viable alternative) availability, cost of technology (fuel cells) and demand.

Forecasting demand to 2050 is complex, but we attempt here to indicate the demand for hydrogen in tonnes in the Region. We use a variety of data sources including UK government data. In effect, we aim to create a ground-up approach to demand forecasting.

Notes

Hydrogen Purity

With the widespread adoption of hydrogen across a range of uses the issue of required purity will become a focus. Different technologies accept different levels of purity. Distribution networks and technologies will need to be aligned.xiii

Hydrogen Storage

An issue with hydrogen is storage. The gas’s very low density means storage at pressure is often needed to achieve a practical density, especially in the case of transport fuels.

This storage density comes at a high cost, in a car with a 700 bar tank (giving a range equivalent to petroleum), the tank will cost $3,500xiv, compared to $51 for an equivalent petrol car. The fuel cell itself is comparable to the cost of an internal combustion petrol engine to manufacture.

Research is taking place to reduce the tank cost and it should be noted that lifetime costs do mitigate this cost, but it is a demonstration of one of the technical challenges hydrogen needs to overcome.

Hydrogen as a combined fuel

Research and innovation are taking place into hydrogen being using in combination with gasoline in transport. For example in trucks, gasoline starts the engine and it then switches to hydrogen, potentially using hydrogen in over 90 per cent of operating time. This technology is available now.xv

However questions remain as to the impact of a combined fuel approach on other emissions, primarily Nitrous Oxidexvi. The ability and cost of diesel technology modification, air quality regulation standards and the cost profile of hydrogen technology will determine the take up of this approach.

For the study we refer to:

- Battery Electric Vehicles (BEV)
- And Fuel Cell Electric Vehicles (FCEV)

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batteries or hydrogen are not practical
3. Looking at hydrogen demand in the Region

In order to study this in more detail and to give clarity to energy demand profiling, we are going to look at the demand for hydrogen across four core sectors and with sub-sectors where relevant.

We will use information from both IRENA and the Hydrogen Council to explain and challenge potential demand scenarios for the Region.

- One - Transport – broken down by mode
- Two - Industrial demand
- Three - Commercial and domestic heating
- Four - Power generation

3.1 Transport

Transport is now the major source of carbon emissions in the UK (over 40 per cent) and representing 27 per cent of energy consumption in the Region. The latter figures excludes international maritime and aviation bunkers. With the presence of major maritime ports and airports in the Region the 27 per cent is likely to be closer to 40 per cent.\(^4\)

Hydrogen in transport is complex for several reasons:

1. The need to link on-vehicle technology with fuelling infrastructure to develop a system approach – commercial fleets with ‘collective on-site refuelling’ are likely to be more attractive to evangelist new fuel users – we call this captured fleets

2. Hydrogen on vehicles needs pressurised storage, the trade-off between range and tank size means in a small vehicle the tank has to be a higher pressure/compact and is relatively more expensive to the total vehicle cost – a small vehicle with a small range is potentially more suited to BEV technology – an example of complexity of replacing one energy source (gasoline – petrol/diesel) with many

3. Battery technology is becoming an established and affordable fuel option in cars, currently Battery Electric Vehicles (BEV) market share of the UK new car market is 4.7 per cent (SMMT). 200 BEV model variants are now available in the UK\(^{xvii}\), as opposed to two Fuel Cell Electric Vehicles (hydrogen)

4. The variation between different transport modes ‘optimal life expectancy’, likely to be 8 to 10 years for a car, over 30 years for a ship or aircraft. Meaning car technology is likely to have three or four replacement cycles before 2050 as opposed to one for a ship or aircraft. Market penetration for new fuels is likely to be higher in modes with a higher number of replacement cycles.

5. Ambitious targets to drive carbon out of the transport fleet, such as the requirement for no internal combustion (2030) or hybrid cars/vans to be sold after 2035, will drive change

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\(^{4}\) Based on London airports accounting for over 60 per cent of international air traffic (ONS) and London, Kent and Essex’s ports accounting for 20 per cent of all maritime traffic (by tonnes, ONS)
So, it is likely the optimal transport mode for hydrogen will need to take into account the following:

- Captive fleet for refuelling
- Larger in size and cost to justify tank cost – based on total vehicle cost and fuel density
- One where battery technology adds weight or long charge times make high vehicle usage case more challenging
- A mode that has a life expectancy that allows for than one replacement cycle between now and 2050
- Where battery technology is not currently being rapidly adapted

| Analysis of hydrogen as a transport fuel source by mode | | |
|---|---|---|---|---|---|---|
| Mode | Optimal lifetime | Replacement cycles in next 30 years (ii) | Captive fleet | Available as Electric | Cost of Tank vs. vehicle cost | likelihood of mass adoption of hydrogen’ by 2050 1 unlikely - likely or Hydrogen fuel as a market share ‘optimum lifespan’ | Analysis vs. Hydrogen Council |
| Small car | 10 | 3 | No | Yes | High | 1 | 10 per cent | Good |
| Medium large car | 10 | 3 | No | Yes | Medium | 2 | 25 per cent | OK |
| Van | 8 | 3.75 | Yes/No | Yes | High | 3 | 40 per cent | Poor |
| Large Truck (i) | 8 | 3.75 | Yes | No | Low | 3 | 22 per cent | Good |
| Buses and coaches | 12 | 2.5 | Yes | Yes | Low | 4 | 35 per cent | Good |
| Rail (where lineside electric is not available) | 30 | 1 | Yes | Yes | Low | 4 | 15 per cent | Poor |
| Maritime (passenger) | 25 | 1.2 | Yes | Yes/No | ? | 2 | 30 per cent | Poor |
| Maritime (freight) | 25 | 1.2 | Yes/No | No | ? | 2 | 5 per cent | Good |
| Aviation | 25 | 1.2 | Yes | No | ? | 1 | 5 per cent | Good |

Captive fleet (single parked location)

(ii) The Geography of Transport Systems... https://transportgeography.org/?page_id=5423

Above we look at the modes and their relative performance against the criteria listed.

The analysis above shows two elements:

1. From what we know now, buses, coaches, trains (where no lineside electric power is available), large trucks and vans are more likely to be earlier and more significant adopters of hydrogen technology than, maritime or aviation.
2. Our analysis is compared to the estimated market share of hydrogen as a fuel source in 2050 by mode (Hydrogen Council). In most cases the match is good, however:
   - Vans - the Hydrogen Council estimates a hydrogen market share of 40 per cent. Vans will be very price sensitive to technology, more so than cars, so the entry point for FCEV might not be clear
   - Rail – the Hydrogen Council estimates a market share of 15 per cent. This has the potential to be higher, but, certainly, in the case of our Region, lineside electricity represents the vast majority of rail service (certainly passenger) therefore hydrogen’s share of the rail network will be lower than the Council’s forecast. In rural and or non-electrified areas it may be higher
• Hydrogen as a maritime fuel is challenging to forecast and is certainly one mode where adoption will be strongly influenced as the result of future regulation. Regulation through the International Maritime Organisation, based in London will set standards globally.

• Aviation is likely to prefer the development of synthetic liquid fuels, for weight and density reasons. This fuel technology will need to be optimised for delivery on the ground and may need a dedicated approach for the sector.

Notes on road transport

Most hydrogen vehicles will be a form of hybrid, they will also have battery power. The ratio of battery power to fuel cell will vary depending on the type of vehicle, cost and market. For this element of the report, we assume that in vehicles classified as FCEV will have hydrogen as the major power source.

Cars

Currently, the Toyota Mirai is one of the two Fuel Cell Electric Vehicles (FCEV) available in the UK, the cost is around £60k. Less than 700 new FCEV cars were registered in 2019. In 2019 there were approximately 4.5 million cars on the road in Kent, Essex and London, about 14 per cent of the UK total. Total registrations are referred to as the parc.

The Hydrogen Council estimates that the FCEV market share for all cars by 2050 will be between 10 and 25 per cent.

The UK government is proposing to outlaw the sales of new conventional (2030) and hybrid powered cars and vans from 2035. This will mean a rapid increase in the share of both BEV and FCEV after that date.

Given the current prominence of battery technology, we have assumed that in 2030 most non IC cars will be battery, but by 2050 each will have a 50 per cent share of the new market – this implies a parc figure of just over 34 per cent for FCEV in 2050. This follows the cost profiling of the respective technologies by McKinsey, illustrated for each mode.

Considerably higher than the Hydrogen Council, but with incentives in London, likely to be extended in geography and scope, not unlikely

Forecasting:

• Future Mileage: We have used the 2018 department of transport forecast of increase in car traffic to 2050. This estimated increase in total vehicle kms of between 11 and 43 per cent, we have used the average value which is 27 per cent.

• We have based fuel consumption of 0.89 kgs per 100 kms, based on four type of fuel cell car currently for sale in Europe.

• Average mileage of 12,000 kms per annum

Based on this data forecast annual demand for hydrogen for cars in the Region is 218,763 tonnes per annum.

Infrastructure:

Based on 218,763 tonnes of demand, the world’s largest hydrogen filling station being capable of delivering 750 kgs per day, allowing for 96 per cent up time, that would
require just over 700 hydrogen filling stations in Kent, Essex in London. Currently in the UK there were 8,385 filling stations for petrol and diesel.

Currently there are just four car accessible filling stations in London, one on the M25 and one at Gatwick. California currently has approximately 50 hydrogen filling stations.

Element Energy, forecasts a need for 6,000 hydrogen filling stations nationally by 2050.

As an example of the challenge for fuel cells in cars the analysis from McKinsey shows that in small cars FCEV are currently twice as costly (over a lifetime) to BEV. Across all car types BEV matches FCEV cost by 2050, so factors such as range and charge time are likely to be critical to car choice.
**Light Goods Vehicles**

There are currently no FCEV’s Light Goods Vehicles (vans) on sale in the UK. Renault is developing and FCEV hybrid, battery is the predominant power source.

Vans are priced competitively, about 40 per cent of the cost of the Toyota Mirai.

However, batteries can reduce the weight and capacity of vans – potentially making FCEV an attractive option.

The need for new vehicles to come to market and to gain market share will impact the total number of vans on the road by 2050. The Hydrogen Council proposed 40 per cent of all vans being fuel cell by 2050. If we apply the same assumption following the outlawing of internal combustion engine vans by 2030 and hybrids by 2035, the FCEV share of vans by 2050 in the Region will be 34.2 per cent, lower than the Hydrogen Council forecast.

Forecasting total demand for hydrogen from the sub-sector:

- We have used the 2018 Department for Transport forecast of increase in van traffic to 2050. This estimated increase in total vehicle kms between 23 and 108 per cent, we have used 66 per cent
- We have based fuel consumption of 0.89 kgs per 100 kms, with an average mileage of 19,000 kms per annum

**Forecast annual demand for hydrogen for cars in the Region is 42,300 tonnes per annum.**
Heavy Goods Vehicles

In 2019 there were 48,000 heavy goods vehicles registered in Kent London and Essex, about 9 per cent of the UK total.

Taking the Hydrogen Council market share forecast of 22 per cent of all HGV’s on the road being FCEV by 2050, this would represent 10,560 LGV’s.

Currently the average LGV travels 51,700 kms per annum

Forecasting:

Total miles for this type of vehicle is expected to increase between 5 and 12 per cent by 2050, an average of 8.5 per cent.

The fuel consumption as a large HGV is estimated at between 7.5 and 8.0 kgs per 100kms\textsuperscript{xxvii} , the average heavy goods vehicle would use approx. 4,200 kgs of hydrogen per annum.

**Giving a total demand in the Region from this sector of 44,400 tonnes per annum.**

This converts to an additional 169 filling stations. In reality, these are likely to be primarily cited at distribution hubs.

In the analysis above BEV and FCEV outperform diesel as a fuel source in 2030. Battery and FCEV have a similar cost path, by potential FCEV gives a greater range and higher payload that BEV.
Given the high density of heavy duty traffic to and from Dover and Tunnel, 11,000 trucks per day, the demand for hydrogen for the sector could increase significantly in the Region. This most likely warrants further study.

**Buses and Coaches**

51 per cent of all bus journeys take place in London, with just 2.7 per cent in Kent and Essex.xxviii

London is currently operating FCEV buses and plans to increase this fleet, hydrogen production for the fleet will be based in Kent, Ryse Hydrogen and Wrightbus

Transport for London buses travelled a total to 475,500,000 kms in 2109/2020xxix. There were 9,100 busses in service, giving an annual kms of 50,044, this is double the national average of 24,386 kms.

For the sake of this study therefore will use a bus and coach weighted average of TfL buses and all buses and coaches in Kent, Essex and London (excluding TfL) to give an average kms of 33,000

So, overall there are 26,300 buses and coaches registered in Kent, Essex and London. We are assuming the Bus and Coach market share will be 40 per cent of the total market, in line with Hydrogen Council forecasts.

The fuel consumption as a large Bus/Coach is estimated at 7.5xxx per 100kmsxxxxi.

**Forecasting**

Total bus and coach journeys declined slightly in 2019 – in the absence of the Department for Transport forecast, we have assumed no change in bus miles in London Kent and Essex between now and 2050.

**Giving a total demand from this sector of 26,075 tonnes per annum.**

This converts to an additional 87 filling stations. In reality, these are likely to be primarily cited at all current bus stations.
Of all the modes FCEV and BEV achieve cost parity to gasoline earliest (2025) and outperform that fuel by the greatest margin. Charge time and refuelling needs are likely to influence technology choice.
Summary for road transport

Summary Table of main mode Transport Consumption, 2050

<table>
<thead>
<tr>
<th>Number registered nationally</th>
<th>Registered in London, Kent and Essex</th>
<th>Per cent</th>
<th>National Average KMS per annum</th>
<th>Total KMS 2019</th>
<th>Average Growth in KMS to 2050</th>
<th>Total KMS 2050</th>
<th>KMS Hydrogen Vehicle Market Share per cent of total market</th>
<th>2050 kms Hydrogen, Kent London Essex</th>
<th>Hydrogen consumption kgs per 100km</th>
<th>Per cent of demand to nearest per cent</th>
<th>Filling Stations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cars</td>
<td>32,884,320</td>
<td>4,571,992</td>
<td>14</td>
<td>12,078</td>
<td>96,591,823,206</td>
<td>27</td>
<td>71,871,615,471</td>
<td>34</td>
<td>24,580,092,491</td>
<td>1</td>
<td>218,763</td>
</tr>
<tr>
<td>Light Goods Vehicles</td>
<td>4,246,348</td>
<td>440,413</td>
<td>10</td>
<td>19,028</td>
<td>8,390,218,611</td>
<td>66</td>
<td>13,911,380,822</td>
<td>34</td>
<td>4,735,623,841</td>
<td>1</td>
<td>42,363</td>
</tr>
<tr>
<td>Heavy Goods Vehicles</td>
<td>525,753</td>
<td>47,967</td>
<td>9</td>
<td>51,735</td>
<td>2,461,588,122</td>
<td>8</td>
<td>2,692,523,113</td>
<td>22</td>
<td>692,355,085</td>
<td>8</td>
<td>44,427</td>
</tr>
<tr>
<td>Buses and coaches</td>
<td>157,467</td>
<td>20,338</td>
<td>17</td>
<td>869,154,000</td>
<td>-</td>
<td>40</td>
<td>347,661,600</td>
<td>8</td>
<td>28,075</td>
<td>8</td>
<td>99</td>
</tr>
</tbody>
</table>

Based on a filling station dispensing 750 kgs per day 365 days per year (250 equivalent operational) 262.5 tonnes per annum based on 10 tonnes per day 365 days per year 3,600 tonnes per annum Percentage based on a ban of internal combustion engines by 2050 and 50% FCEV/BEV market share for 2045

Our estimates give a total demand for hydrogen in the Region for road transport of about 331,600 tonnes per annum for the Region by 2050.

This will not only require significant investment in transport technology, but also re-fuelling infrastructure. As we may see with battery electric vehicle charging points, it may be the fuelling infrastructure that is the limiting or defining factor to market expansion.

Notes

We estimate that 26.45 per cent of demand for hydrogen will come from buses, trucks and commercial vehicles.

According to our Energy Transition Outlook, most vehicles will be non-combustion models by 2050(1). We estimate that more than 80% of H2 demand for mobility will then be for buses, trucks and other heavy vehicles.xxxi DNV GL

This is at odds with the view of DNV GL, who see the majority of hydrogen vehicles being commercial and public transport. The key to this outcome is the share of BEV and FCEV vehicles, and that is likely to be dependent on:

- Cost profiles of technologies
- Recharging availability
- Technology – particularly with charging time and range in mind.

Forecast Road Transport Demand for hydrogen in 2050, 331,607 tonnes per annum
Aviation

When we include international bunkers, aviation now accounts for 9 per cent of UK derived CO2 emissions (see Annex 1).

It is unlikely that hydrogen in its base state will play a role in aviation. Issues with storage and density are key. The most likely route for aircraft decarbonisation is synthetic biofuels and efuels (which would involve hydrogen).

Challenges at the moment include:

1. The current low cost of aviation fuel £0.47 per litre\textsuperscript{xxxiii}, petroleum prices are currently between £1.10 and £1.18 per litre\textsuperscript{xxxiv}
2. The need for dedicated resources for synthetic fuel and e-fuel production will be costly and therefore where might they be sited in relation to demand? (Fawley close to Southampton currently has a dedicated supply pipeline to Heathrow)
3. The international nature of the sector makes gaining agreement on low or zero carbon strategy challenging

It is therefore difficult to forecast the demand for hydrogen-based products for aviation. The Hydrogen Council forecast the sector will have just 5 per cent of the fleet on hydrogen-based efuels by 2050.

However, with 60 per cent of passenger traffic from the UK out of London airports, and 27 per cent of that being from Heathrow on its own, this does warrant specific investigation.

Marine

In some ways not dissimilar to aviation, marine fuel was trading in April 2020 at between 8 and 12 pence per litre\textsuperscript{xxxv}.

As with other technologies an important co-driver of climate change policy will be air quality improvements. The International Maritime Organisation (IMO) introduced significant revised air quality standards in 2020, to implement the adoption of low-sulphur fuels and technology. Changes in marine fuels have a significant global impact on emissions and pollution. By not reducing the SOx limit for ships from 2020, the air pollution from ships would contribute to more than 570,000 additional premature deaths worldwide between 2020-2025.\textsuperscript{xxxvi}

Investment replacement cycles for vessels are long, in reality a new vessel or coming into service today will still be in service in 2050. So demand for clean fuels will need to cater for legacy and retrofit, make the financial case compelling or be enforced by regulation, there is little sign of this yet.

*Shipping is a capital-intensive industry characterised by large, long-life assets, thin margins and a high-dependence on a global supply of energy-dense fuels. These characteristics make decarbonisation complex and expensive, with one study estimating the total cost at $1.65 trillion by 2050.*\textsuperscript{xxxvii}

IMO has announced an ambition to at least halve international shipping greenhouse gas (GHG) emissions by 2050, while reducing CO$_2$ emissions intensity by at least 40 per cent by 2030, and pursuing efforts towards 70 per cent by 2050, relative to a 2008 baseline.
The current Hydrogen Council forecast for demand from hydrogen in the sector is just five per cent by 2050.

The question in the sector seems to be ‘what fuel and propulsion systems?’. As in many other sectors it is likely a multiple fuel will replace a single fuel. This is a summary of the options:

<table>
<thead>
<tr>
<th>Technological measures to improve ship-design efficiency</th>
<th>Use of alternative zero-carbon fuels or energy sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light construction materials</td>
<td>Batteries to power ships</td>
</tr>
<tr>
<td>Slender design</td>
<td>Hydrogen fuel cells</td>
</tr>
<tr>
<td>Propulsion-improvement devices</td>
<td>Hydrogen as fuel for internal combustion engines</td>
</tr>
<tr>
<td>Bubulous bows</td>
<td>Ammonia fuel cells</td>
</tr>
<tr>
<td>Air lubrication systems</td>
<td>Ammonia as fuel for internal combustion engines</td>
</tr>
<tr>
<td>Advanced hull coating</td>
<td>Synthetic diesel</td>
</tr>
<tr>
<td>Ballast water-system design</td>
<td>Synthetic methane</td>
</tr>
<tr>
<td>Energy-efficiency measures</td>
<td>Advanced biofuels</td>
</tr>
<tr>
<td>Engine and auxiliary systems improvement</td>
<td>Electricity to power ships</td>
</tr>
</tbody>
</table>

Sources: Organization for Economic Cooperation and Development and International Transport Forum, 2018, Decarbonizing Maritime Transport: Pathways to Zero-carbon Shipping by 2050; European Federation for Transport and Environment, 2018, Road Map to Decarbonizing European Shipping; University Maritime Advisory Services, 2019, How can shipping decarbonize?

In terms of the Region, 21 per cent of all UK cargo travels through ports in the Region. 23 per cent of natural gas through a single terminal on the Isle of Grain in Kent.xxxviii. Proximity to intensive shipping routes in the North Sea and Channel make the location ideal for production, storage and distribution of low carbon clean fuels.

At this point defining those fuels, when the value gap is so significant, is in reality not practical. But should be a focus of research in the Region, given the level of traffic and intensity of marine traffic.

**Rail**

Trials and research is happening in the UK into hydrogen trains. Porterbrook, a major provider of rail passenger rolling stock to UK train companies is working with the University of Birmingham to deliver a working bi mode (electric and hydrogen) train.xxxix

On the face of it, in the South East of England, the vast percentage of the rail network is electrified, with a small number of lines in Sussex, Surrey and Essex not so. Most likely less than five per cent of passenger trains are non-electrified as the map below shows.
However, there may be opportunities in the future for hydrogen being utilised on short journeys where the maintenance of electrified infrastructure could be eliminated.
3.2 Domestic and commercial gas supply

One of the most comprehensive studies into the use of hydrogen in the gas network has taken place in Leeds. – H21xli.

This report summarizes that to supply Leeds with 100 per cent hydrogen would equate the need to have a generation capacity of 151,000 tonnes of hydrogen per annum (1,024 MW produced from four 256 MW electrolysers).

It has been demonstrated that the current UK gas grid, and gas use technology (boilers) could cope with up to a 20 per cent hydrogen contact without modification. However, to go beyond this would need a programme in scope similar to the conversion from town gas to natural gas in the 1960’s and 1970’s.

The forecast production capacity is to cope with the peak seasonal demand. The Leeds hydrogen average demand (for residential and commercial) is estimated 732 MW, equating to 107,836 tonnes of hydrogen per annum.

To extrapolate this to the Region.

The number of households in Leeds equates to 1.41 per cent of the English total.

The number of households in Kent, London and Essex equates to 21.63 per cent of the English total

The Number of business in Leeds equates to 1.21 per cent of the English total.

The number of businesses in Kent, London and Essex equates to 31.27 of the English total. The KLE Region’s business representation is higher
So, on a like for like basis, supplying the Region with 100 per cent hydrogen would equate to 2,000,978 tonnes per annum, taking into account the relative higher percentage of businesses in the Region.

The H21 report looked specifically at providing 100 per cent hydrogen to London, as the last city in a national hydrogen roll out plan. H21 did not plan to convert London to 100 per cent hydrogen until between 2045 and 2052.

The capital investment required to convert London to 100 per cent hydrogen gas supply is considerable, estimated at over £17,000m in 2016.

Trials in other parts of the UK have blended up to 20 per cent hydrogen into the gas grid, without modification to the equipment. Keele University\(^{xlii}\)

The Hydrogen Council forecast 20 per cent hydrogen in the gas grid by 2050.

So, in terms of the Region we assuming two scenarios of demand in 2050. One is 20 per cent supply through the current grid, with no equipment conversion. The other demand, 40 per cent, this is assuming full hydrogen conversion for London, Kent and Essex has started in 2045 and is part way through the programme, but not completed.

**Hydrogen at 20 per cent of demand - 400,196 tonnes per annum**

**Hydrogen at 40 per cent of demand – assuming a 2045 start date and 2052 end date from H21 analysis  800,391 tonnes per annum**
3.3 Large Industrial users

Data used here is the NAEI Emissions for 2017. CO2 emissions, large energy users (excluding power generation) and DUlkes energy consumption by sector.

The NAEI database breaks carbon emissions down to site level and has been determined as a best means to select large energy consumers in the Region.

On this basis the Region top 50 energy emitters represent 5.13 per cent of the England’s total heavy industry carbon emissions, excluding the power generation sector, as detailed on the NAEI database.

We have now aggregated into primary sectors the top 50 carbon emitters in the Region (who represent 86 per cent of total non-power emissions) by sector.

From the DUlkes database we can see the percentage of energy by sector, by fuel type – we have taken the percentage of gas.

<table>
<thead>
<tr>
<th>Sector</th>
<th>Tonnes Carbon in Region</th>
<th>Tonnes nationally</th>
<th>Per cent Region</th>
<th>Total Energy UK large emitters</th>
<th>Gas KtOE</th>
<th>Per cent gas</th>
<th>Assumption Gas KtOE</th>
<th>Conversion to Kwe</th>
<th>Tonnes Hydrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper, printing &amp; publishing industries</td>
<td>171,236</td>
<td>399,914</td>
<td>42.82</td>
<td>1,080.00</td>
<td>337.00</td>
<td>33.67</td>
<td>14.30</td>
<td>1,678,169.718</td>
<td>50,350.13</td>
</tr>
<tr>
<td>Food, drink &amp; tobacco industry</td>
<td>58,314</td>
<td>735,901</td>
<td>7.92</td>
<td>3,109.61</td>
<td>1,808.31</td>
<td>58.09</td>
<td>143.13</td>
<td>1,664,647.02</td>
<td>49,944.41</td>
</tr>
<tr>
<td>Other mineral industries</td>
<td>61,765</td>
<td>849,057</td>
<td>7.27</td>
<td>2,688.16</td>
<td>1,276.00</td>
<td>47.45</td>
<td>92.82</td>
<td>1,079,522.486</td>
<td>32,388.91</td>
</tr>
<tr>
<td>Vehicles</td>
<td>12,236</td>
<td>136,170</td>
<td>9.03</td>
<td>1,365.71</td>
<td>458.00</td>
<td>32.98</td>
<td>41.36</td>
<td>480,680.773</td>
<td>14,420.87</td>
</tr>
<tr>
<td>Chemical industry</td>
<td>27,817</td>
<td>2,087,839</td>
<td>1.35</td>
<td>3,667.81</td>
<td>1,864.58</td>
<td>50.84</td>
<td>24.85</td>
<td>268,947.783</td>
<td>8,669.30</td>
</tr>
<tr>
<td>Non-ferrous metal industries</td>
<td>5,027</td>
<td>60,880</td>
<td>8.29</td>
<td>648.21</td>
<td>272.39</td>
<td>41.96</td>
<td>22.57</td>
<td>262,462.720</td>
<td>7,973.47</td>
</tr>
<tr>
<td>Waste collection, treatment &amp; disposal</td>
<td>337,757</td>
<td>1,286,694</td>
<td>26.25</td>
<td>86.00</td>
<td>17.00</td>
<td>19.77</td>
<td>4.46</td>
<td>51,898.782</td>
<td>1,557.12</td>
</tr>
<tr>
<td>Total</td>
<td>874,211</td>
<td>5,556,055</td>
<td>12.13</td>
<td>12,266.50</td>
<td>6,031.27</td>
<td>49.16</td>
<td>731.38</td>
<td>5,906,629.303</td>
<td>185,215.40</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sector</th>
<th>Tonnes</th>
<th>Per cent</th>
<th>Total Energy</th>
<th>Gas KtOE</th>
<th>Per cent</th>
<th>Conversion to Kwe</th>
<th>Tonnes Hydrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>All large emitters (non power)</td>
<td>13,154.857</td>
<td>20 per cent hydrogen</td>
<td>33,043.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Per cent Region Heavy Emitters</td>
<td>5.13</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The table above shows the sectors with significant Carbon emissions, for example 42 per cent of England’s paper industry emissions are from the Region, nine per cent for vehicles, but only 1 per cent for the chemical industry.

Typically gas presents 50 per cent of energy consumption, electricity being the other significant energy source. We are assuming this gas element is most suitable to convert to hydrogen.

Accepting a large number of assumptions the total demand from the 50 most significant energy emitters in the Region is estimated at 166,215 tonnes per annum hydrogen equivalent.

Focusing on a 20 per cent conversion rate this would translate to 33,048 tonnes of hydrogen per annum.

This sector may well be underestimated, as it is not clear from data where gas is consumed direct from the grid, those organisations will be accounted for as part of the domestic and commercial gas consumption data. Nor where competition ruling is not permitting disclosing gas consumption, hence the use of emissions as a proxy.
3.4 Power generation

What is the pathway to using hydrogen to generate electricity?

It is estimated that by 2030 current Combined Cycle Gas Turbine (CCGT) technology can be replaced by power generation that uses 100 per cent hydrogen – most likely produced from LNG with associated carbon capture and storage. These plants are known as H2GTs.

However, a recent ETI report (Salt Cavern Appraisal for Hydrogen and Gas Storage, 2018) estimates that large scale H2GTs, without any such problems, will be available by 2029-2030. Major turbine manufacturers already pledge support to developing new H2GTs capable of burning 100% hydrogen at similar efficiencies to current CCGTs and very low NOx emissions, which would not require additional capture plants.

Hy-Impact Series, Study 3: Hydrogen for, Power Generation

In Japan trials have successfully taken place to run CCGT’s at 30 per cent hydrogen. As detailed by Mitsubishi Power.

Element Energy have a number of scenarios for this sector that include remaining with gas base technology and offsetting carbon emissions, or switching to hydrogen (green or blue) as a fuel.

Power companies’ CCGT replacement strategies are critical here. The Dutch are currently modifying a CCGT plant to run on 100 per cent hydrogen.

Mitsubishi Power of Japan is dedicated to achieving 100 per cent hydrogen combustion by 2025.

At present it estimates that a 500MW CCGT running on 20 per cent hydrogen will consume 1.4 tonnes of hydrogen per hour, or approximately 12,250 tonnes per year.

In effect the current CCGT power stations in in Kent and Essex (with a generating capacity of 3,602 MW) were to use 20 per cent hydrogen.

This would require 88,250 tonnes per annum.
4. **Suggested further research**

The following items cover some of the aspects that may help in identifying and approaching future work:

1. The implementation of the policy to only allow battery electric vehicles and fuel cell electric vehicles to be sold in the UK new from 2030 – implications on battery hydrogen split by 2050

2. The opportunity for decarbonisation of heavy vehicle road freight

3. What path will aviation take for decarbonisation? What is the future link between fuels manufacture and demand locations?

4. How much marine fuel is being used in the Region – what is the path to decarbonisation for the sector?

5. The timing and approach to the conversion of the UK gas grid to all or blend of hydrogen

6. How might combined-cycle generation technology (CCGT) be replaced and when? Can we optimise CCGT demand for electricity with domestic and commercial gas?

7. How might large industrial energy users in the Region decarbonise, will new technologies or the attraction of electricity change the hydrogen demand profile?

8. How will challenges such as the purity of hydrogen needed for different technologies and future technology efficiency change demand and distribution profiling?

9. How to address seasonality of demand (winter) without over investing in capacity

*(December 2020)*
Appendix

Hydrogen Demand report Annex's

There is a variety of dataset and methods to record energy production, energy consumption and CO2 emissions on the UK – as well as a variety of units.

This paper looks at the following sources:

**Overall breakdown and change in CO2 emissions**

National and International CO2 emissions: Estimated territorial emissions of carbon dioxide (CO2) by source category, 1970-2018 (MtCO2e), Emissions of all carbon dioxide for the UK from 1970-2018 by source sector, BEIS

**Energy Consumption by local authority**

Sub-national total final energy consumption in the United Kingdom, (2005 - 2017), BEIS

*This will not include power stations and large industrial sites so will underestimate energy consumption at regional level, but this has been resolved through the Heavy Industry and Power Generation work*

**National Atmospheric Emissions Inventory for large industrial and commercial emitters of CO2**

Emissions from Point sources as calculated for the 2017 NAEI maps

Due to different methods of calculation and sector definitions it is not always possible to compare one data set to the other.
### Annex 1: UK and UK/International quantified CO2 emissions

**Estimated territorial emissions of carbon dioxide (CO₂) by source category, UK 1990 and 2018**

Coverage: United Kingdom

<table>
<thead>
<tr>
<th>Million tonnes carbon dioxide equivalent (MtCO₂e)</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy supply</td>
<td>242.1</td>
<td>98.4</td>
<td>143.7</td>
<td>-59.37</td>
<td>38.11</td>
<td>24.00</td>
<td>Decrease as a result of the replacement of coal fired power stations</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>with gas and increase in renewables</td>
</tr>
<tr>
<td>Business</td>
<td>111.6</td>
<td>65.9</td>
<td>45.5</td>
<td>-41.92</td>
<td>18.06</td>
<td>18.09</td>
<td>Sourcing cleaner energy, increase in energy efficiency</td>
</tr>
<tr>
<td>National Aviation</td>
<td>1.5</td>
<td>1.5</td>
<td>0.0</td>
<td>-0.09</td>
<td>0.24</td>
<td>0.36</td>
<td>National aviation just 4 per cent of aviation emissions in 2018</td>
</tr>
<tr>
<td>Road Transport</td>
<td>108.0</td>
<td>111.7</td>
<td>-3.7</td>
<td>3.42</td>
<td>17.45</td>
<td>27.27</td>
<td>Only national sector to increase emissions</td>
</tr>
<tr>
<td>Railways</td>
<td>2.0</td>
<td>1.8</td>
<td>0.2</td>
<td>-0.96</td>
<td>0.32</td>
<td>0.43</td>
<td>Emissions down due to energy efficient trains and use of electrified services</td>
</tr>
<tr>
<td>National Shipping</td>
<td>8.4</td>
<td>5.8</td>
<td>2.6</td>
<td>-30.32</td>
<td>1.35</td>
<td>1.43</td>
<td>National shipping 43 per cent of shipping emissions</td>
</tr>
<tr>
<td>Public</td>
<td>15.4</td>
<td>8.0</td>
<td>7.4</td>
<td>-40.38</td>
<td>2.16</td>
<td>1.95</td>
<td>Sourcing cleaner energy</td>
</tr>
<tr>
<td>Residential</td>
<td>78.3</td>
<td>69.4</td>
<td>11.9</td>
<td>-15.17</td>
<td>12.64</td>
<td>19.20</td>
<td>Smaller decline due to continued reliance of gas as a fuel</td>
</tr>
<tr>
<td>Agriculture</td>
<td>6.5</td>
<td>5.7</td>
<td>0.7</td>
<td>-11.41</td>
<td>1.05</td>
<td>1.46</td>
<td>As a sector national emissions are offset by forestry</td>
</tr>
<tr>
<td>Industrial processes</td>
<td>19.4</td>
<td>9.7</td>
<td>9.7</td>
<td>-50.05</td>
<td>3.13</td>
<td>2.37</td>
<td>Sourcing cleaner energy and reduced large scale industrial activity</td>
</tr>
<tr>
<td>Land use, land use change and forestry</td>
<td>-2.4</td>
<td>-11.7</td>
<td>9.3</td>
<td>387.18</td>
<td>-0.39</td>
<td>-2.86</td>
<td>Forest planting and less conversion to cropland</td>
</tr>
<tr>
<td>Waste management</td>
<td>1.3</td>
<td>2.2</td>
<td>1.1</td>
<td>-81.79</td>
<td>0.21</td>
<td>0.06</td>
<td>More efficient Energy from Waste</td>
</tr>
<tr>
<td>National Total</td>
<td>586.7</td>
<td>363.7</td>
<td>223.1</td>
<td>-38.62</td>
<td>96.23</td>
<td>93.24</td>
<td></td>
</tr>
<tr>
<td>International aviation bunkers</td>
<td>15.4</td>
<td>36.3</td>
<td>-20.9</td>
<td>136.24</td>
<td>2.48</td>
<td>8.86</td>
<td>More than doubled</td>
</tr>
<tr>
<td>International Shipping</td>
<td>8.8</td>
<td>7.8</td>
<td>1.0</td>
<td>-2.90</td>
<td>1.29</td>
<td>1.90</td>
<td></td>
</tr>
<tr>
<td>International Total</td>
<td>23.4</td>
<td>44.1</td>
<td>-20.7</td>
<td>88.74</td>
<td>3.77</td>
<td>10.76</td>
<td></td>
</tr>
<tr>
<td><strong>GRAND TOTAL</strong></td>
<td>619.1</td>
<td>409.8</td>
<td>209.3</td>
<td>-33.81</td>
<td>100.00</td>
<td>100.00</td>
<td></td>
</tr>
<tr>
<td>Transport all</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>23.14</td>
<td>40.25</td>
<td></td>
</tr>
<tr>
<td>Transport National</td>
<td>10.36</td>
<td>27.4</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Notes:
1. The entire time series is revised each year to take account of methodological improvements.
2. Emissions shown in this table in previous years by fuel type are now presented in table 17 and by end user in table 20.
Annex 2: London, Kent and Essex Energy Consumption

Total final energy estimates at a regional and local level in 2017 are based on consumption statistics from the following four sub-national consumption datasets:

Data is in GWh

Short Summary

<table>
<thead>
<tr>
<th></th>
<th>Coal and Manufactured Fuels</th>
<th>Petroleum products (2)</th>
<th>Gas</th>
<th>Electricity</th>
<th>Bioenergy &amp; wastes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Industrial &amp; Commercial</td>
<td>Domestic</td>
<td>Road transport</td>
<td>Rail</td>
<td>Public Sector</td>
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<tr>
<td>ESSEX</td>
<td>343.47</td>
<td>1,239.40</td>
<td>529.72</td>
<td>14,405.47</td>
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<tr>
<td>KENT</td>
<td>438.70</td>
<td>1,071.28</td>
<td>561.84</td>
<td>13,707.63</td>
<td>42.32</td>
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<tr>
<td>LONDON</td>
<td>172.86</td>
<td>2,360.58</td>
<td>190.00</td>
<td>27,404.92</td>
<td>217.97</td>
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<tr>
<td>KLE total</td>
<td>955.09</td>
<td>4,571.60</td>
<td>1,311.53</td>
<td>55,918.02</td>
<td>369.35</td>
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</tbody>
</table>

England

<table>
<thead>
<tr>
<th></th>
<th>Coal and Manufactured Fuels</th>
<th>Petroleum products (2)</th>
<th>Gas</th>
<th>Electricity</th>
<th>Bioenergy &amp; wastes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Industrial &amp; Commercial</td>
<td>Domestic</td>
<td>Road transport</td>
<td>Rail</td>
<td>Public Sector</td>
</tr>
<tr>
<td>28,471.30</td>
<td>73,767.5</td>
<td>15,623.8</td>
<td>364,104.8</td>
<td>6,480.8</td>
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</table>

Per cent KLE of England

<table>
<thead>
<tr>
<th></th>
<th>Coal and Manufactured Fuels</th>
<th>Petroleum products (2)</th>
<th>Gas</th>
<th>Electricity</th>
<th>Bioenergy &amp; wastes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Per cent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Per cent KLE</td>
<td>3.35</td>
<td>6.20</td>
<td>8.40</td>
<td>15.33</td>
<td>5.69</td>
</tr>
<tr>
<td>Per cent</td>
<td>0.47</td>
<td>2.23</td>
<td>0.64</td>
<td>27.22</td>
<td>0.10</td>
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Renewable Energy Database March 2020

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<thead>
<tr>
<th>Operational</th>
<th>Under Construction</th>
<th>Planning granted</th>
<th>Planning submitted</th>
<th>TOTAL</th>
<th>TOTAL</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Essex</td>
<td>Kent</td>
<td>London</td>
<td>Essex</td>
<td>Kent</td>
<td>London</td>
<td>Essex</td>
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<tr>
<td>Advanced Conversion Technology</td>
<td>Anaerobic Digestion</td>
<td>Battery</td>
<td>Biomass (dedicated)</td>
<td>EW Conversion</td>
<td>Landfill Gas</td>
<td>Sewage Sludge Digestion</td>
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<td>3.0</td>
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<td>5.8</td>
<td>1.8</td>
<td>-</td>
<td>-</td>
<td>2.0</td>
</tr>
<tr>
<td>79.0</td>
<td>40.0</td>
<td>0.2</td>
<td>10.0</td>
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<tr>
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<tr>
<td>-</td>
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<td>92.0</td>
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<td>26.0</td>
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<tr>
<td>68.8</td>
<td>11.5</td>
<td>20.5</td>
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<td>40.4</td>
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<td>1.1</td>
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<td>30.6</td>
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<tr>
<td>506.3</td>
<td>573.7</td>
<td>257.4</td>
<td>11.8</td>
<td>49.4</td>
<td>49.0</td>
<td>260.9</td>
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<tr>
<td>TOTAL</td>
<td>2,558.0</td>
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</tr>
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</table>

Wind Offshore Kent and Essex | 1,264.3 |

Vattenfall extension (Kent) extension refused June 2020

| Source: Renewable energy planning database, including operational, under construction, planning permission granted, planning permission submitted |

<table>
<thead>
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<tr>
<td>Essex</td>
<td>Kent</td>
<td>London</td>
<td>Essex</td>
<td>Kent</td>
<td>London</td>
</tr>
<tr>
<td>57.3</td>
<td>96.9</td>
<td>486.9</td>
<td>105.1</td>
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<tr>
<td>56.6</td>
<td>11.8</td>
<td>260.5</td>
<td>44.3</td>
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<tr>
<td>257.4</td>
<td>49.0</td>
<td>79.2</td>
<td>98.0</td>
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<td>197.7</td>
<td>817.7</td>
<td>244.6</td>
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63. Source: Individual ports traffic, by cargo type and international or domestic, Maritime Statistics Total for
all ports, all traffic types in 2018 was 472,056,000 tonnes


Hy-Impact Series Study 3: Hydrogen for Power Generation Opportunities for hydrogen and CCS in the UK power mix

(December 2020)