Decarbonisation Pathway for Greater Manchester

Reaching carbon-neutrality in a balanced scenario by 2038

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[1] On October 11, 2019, Guidehouse LLP completed its previously announced acquisition of Navigant Consulting Inc. In the months ahead, we will be working to integrate the Guidehouse and Navigant businesses. In furtherance of that effort, we recently renamed Navigant Consulting Inc. as Guidehouse Inc.

EXECUTIVE SUMMARY

The Greater Manchester Combined Authority (GMCA) has set out a bold ambition for Greater Manchester (GM) to become net zero carbon by 2038, aligning it with the objectives of the Paris Agreement. This target places GM on an accelerated trajectory compared to the rest of the United Kingdom, which is set to reach carbon neutrality in 2050, 12 years later. To support GMCA's ambition, Electricity North West (ENWL) and Cadent Gas have commissioned Navigant to create a net-zero energy scenario for 2038 and to outline a pathway to achieve this vision.

The scale of change required for GM's urban fabric, its residents' lifestyle and the way businesses operate is truly unprecedented and will require concerted effort from all stakeholders. GM's existing building stock will have to be upgraded and heating technology replaced with zero carbon options. Commuters will be encouraged to walk or cycle, whilst all transport will be decarbonised. Industrial processes will have to be re-engineered to run on renewable electricity and low-carbon hydrogen instead of conventional fuels. The monumental effort to bring about these changes can provide GM with first-mover economic advantages compared to regions that are on a less ambitious pathway.

Several broader developments will help GM achieve its net-zero target. The UK government is developing a series of policies that will drive the energy transition in various sectors, whilst the cost of renewable technologies continues to fall, and consumers gradually change their behaviour. Located in the North West of England, Greater Manchester could benefit from a significant hydrogen production potential expected to be unlocked in that region and which will provide a low-carbon alternative to the role natural gas plays today.

The change in energy demand and supply, pathway tracks and key actions for GMCA that are the outcomes of the work presented here are collectively depicted in an infographic and discussed in more detail below.

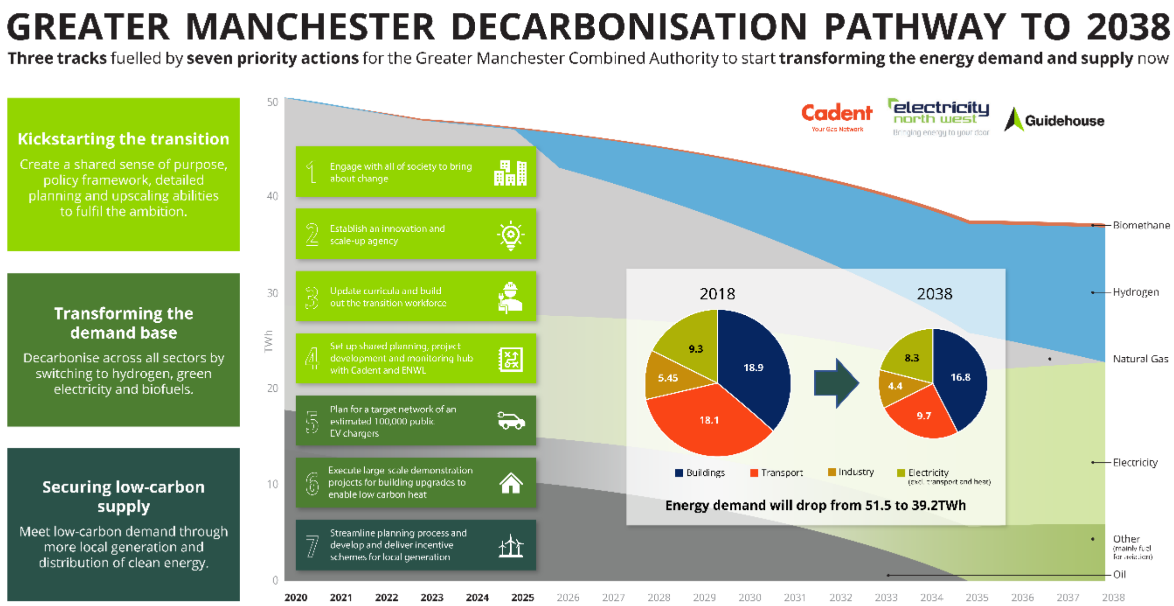


Figure 1: Infographic introducing the decarbonisation pathway for Greater Manchester.

A Balanced Scenario for 2038

Navigant has developed a Balanced Scenario for GM to reach carbon neutrality in 2038, in which low carbon and renewable gases are used in a balanced combination with renewable electricity. This scenario is based on the *Pathways to Net-Zero: Decarbonising the Gas Networks in Great Britain*[2] study prepared by Navigant for Energy Networks Association (ENA).

By 2038, the majority of energy consumed in GM in this scenario will be electricity (18.7TWh) followed by hydrogen (14TWh). Like most urban areas, Greater Manchester is expected to remain a net importer of energy. Whilst around 2TWh of electricity will be produced locally, mainly through solar photovoltaic (PV) and waste-from-energy, the remaining 16.7TWh will have to be imported from the GB power system via National Grid. Remaining emissions in 2038 attributable to electricity imports from a not fully decarbonised nationwide electricity system will need to be offset. Whilst the majority of hydrogen will come from the HyNet project currently being developed in Cheshire, around a fifth of hydrogen consumed in 2038 is expected to be regionally produced green hydrogen.

The building sector is expected consume the largest share of hydrogen, but it is important to note that hydrogen and electrification policy are yet to be fully developed and that there is still uncertainty around the policies that support the decarbonisation of heat in homes. The Balanced Scenario assumes the most cost-effective pathway to net zero carbon based on property types and a large-scale energy efficiency retrofit programme.

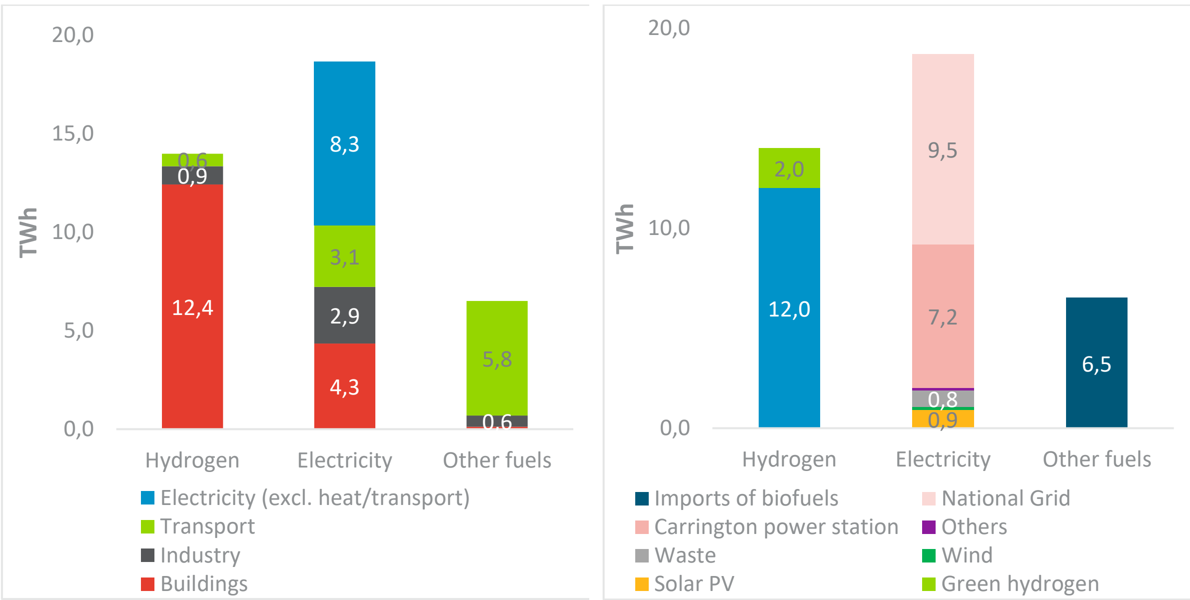


Figure 2: 2038 Greater Manchester energy demand (left-hand side) and supply (right-hand side), by energy carrier

In our Balanced Scenario, energy consumption in GM will undergo a profound transformation over the next 18 years: carbon-intensive oil and natural gas will be gradually phased out and replaced by zero-carbon fuels in the form of renewable electricity and hydrogen. GM's energy demand will also decline from 52TWh today to 39TWh in 2038 on the back of improved energy efficiency, despite a growing population and economy.

[2] Navigant Consulting. *Pathways to Net-Zero: Decarbonising the Gas Networks in Great Britain*. Available at: https://www.energynetworks.org/assets/files/gas/Navigant%20Pathways%20to%20Net-Zero.pdf

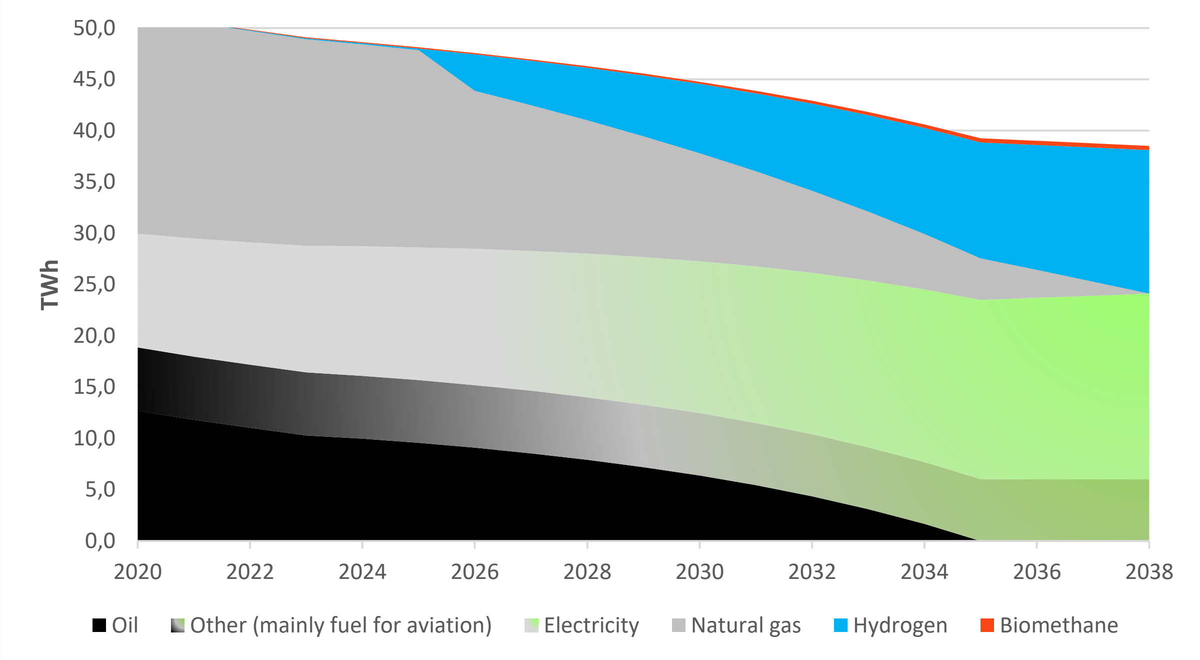


Figure 3: Evolution of energy consumption in Greater Manchester[3]

A three-pronged pathway fuelled by seven priority actions to deliver the Balanced Scenario

We have developed a pathway, or high-level implementation plan, to deliver this 2038 Balanced Scenario for Greater Manchester (GM) along three main tracks:

1. **Kickstarting the transition** – Create a shared sense of purpose, policy framework, detailed planning and upscaling abilities to fulfil the ambition

2. **Transforming the demand base** – Decarbonise across all sectors by switching to hydrogen, green electricity and biofuels

3. **Securing low-carbon energy supply** – Meet low-carbon demand through more local generation and distribution of imported clean energy.

For each track, actions have been identified for four consecutive five-year periods. Seven priority actions across the three tracks that are recommended to the Greater Manchester Combined Authority for the current five-year period are detailed.

[3] The chart covers energy consumed in the three key demand sectors: buildings, transport and industry. “Oil” refers to oil products used in road transport, i.e. petrol for different types of vehicles; “other” mainly consists of fuel for aviation (kerosene or bio-kerosene) and secondary fuels in industry (e.g. biomass); “electricity” includes distributed and grid electricity (the carbon intensity of which declines with time); “natural gas” refers to consumption of methane in buildings and industry; “hydrogen” refers to consumption of hydrogen in buildings and industry; “biomethane” refers to biomethane consumed in transport as bio-CNG or bio-LNG.

		Priority Actions for the GMCA
Kickstarting the Transition	1	GMCA should make its decarbonisation ambition an integral part of its identity, create a common sense of purpose elevating its profile as a leading, innovative and green city. To raise social awareness, the GMCA should develop a communication strategy including integrated branding, urban and on-line presence which clearly sets out the vision, explains the motivation and strategy. User-friendly learning resources should be prepared explaining the climate action GM's residents and businesses should take.
	2	GMCA should collaborate with local higher educational institutions, establish an innovation and scale-up agency that helps mature mid-TRL (technology readiness level) products, services and supporting business models.
	3	GMCA should collaborate with Cadent and ENWL, vocational schools, businesses and others to develop the skills and resource pool required for the net-zero ambition in an accelerated timeframe. To achieve the appropriate rate of building interventions, a dedicated workforce of 20,000 trained contractors will be required by 2025. Digitalising workflows can help achieve the required efficiency levels and execution speed.
	4	GMCA should lead the formation of a shared planning, monitoring and resource hub with Cadent and ENWL that provides data-driven insight into network capacity, spatial planning, tracks progress and can act as an advisory body for participants in the building, industry and transport sectors on the nature and timing of interventions.
Transforming the demand base	5	GMCA should work with the building sector to execute large-scale demonstration projects (1000+ homes) for building upgrades which include building insulation, low carbon heating systems and supporting hydrogen-ready devices (boilers, cookers etc.)
	6	GMCA needs to work with ENWL to plan for a target network of an estimated 100,000 public EV chargers throughout Greater Manchester. Implement incentives for charging network operators to install 19,000 public EV chargers by 2025
Securing low-carbon supply	7	GMCA should streamline and shorten planning permission processes, identify key development areas and develop incentive schemes to: • Expand the local uptake of rooftop solar PV to reach 200MW installed capacity by 2025 • Onshore wind development in Greater Manchester • Develop energy-from-waste and biomass plants

Kickstarting the transition

GM's net-zero carbon target has the potential to fundamentally change the region, positioning it as the energy transition lighthouse of the UK. This brings benefits that go beyond those of the decarbonisation itself by creating a metropolitan region that combines exceptional liveability with economic strength and resilience.

In the first five years of our pathway, key actions need to be taken to kickstart this transition that lay the foundation for a successful transformation, building on the work already undertaken to date by GMCA and incorporating ongoing and planned efforts, such as those highlighted in the recently published Environment Report[4]. The focus in this period is on mobilising enthusiasm and creating

[4] Environment Report 2019-2020, Greater Manchester Combined Authority

trust, defining a clear policy framework underpinned by innovative business and financing models, capacity building of skills and resources, and moving from planning to implementation at scale.

GMCA's ambitious decarbonisation target requires the region to come together and unite behind this goal. To develop and maintain momentum, the vision for the future should be combined with short-term goals that have tangible benefits for residents and business alike. Successes need to be celebrated early on to demonstrate progress.

Clear national policy and regulatory guidance are of key importance to achieving regional goals. Not only do they define the boundaries within which regional authorities have to operate, they also ensure a level playing field and provide clarity needed to unlock much needed investments. Such regulatory and policy frameworks for hydrogen, low carbon heat including the replacement for the renewable heat incentive, a viable replacement for the ill-fated Green Deal and long term nuclear power development do not yet exist at the level needed. GMCA will need to influence their timely development and in some cases develop its own solutions ahead of national policy.

A successful transformation requires the availability of mature sustainable solutions and a large resource pool with the right skills. Innovation is required to ensure that current nascent technologies can be rapidly developed into robust, commercially viable products and solutions that can be deployed at scale. In parallel, a large, skilled workforce needs to be built that can deliver the transformation across all sectors.

Perhaps most importantly, a central planning and monitoring hub should be created that can provide integrated whole of system transition planning. Engagement in this between GMCA, local authorities, Cadent and ENWL is a precondition for success. This planning hub can monitor key performance indicators to track progress and ensure key milestones are achieved on time, and focus is maintained.

Transforming the demand base

Each of the demand sectors (Buildings, Transport, Industry) is characterised by markedly different challenges when it comes to decarbonisation that will require a different approach to interventions and a different role for GMCA.

The buildings sector is arguably the most important as it accounts for over half of total energy demand by 2038. The energy efficiency of GM's building stock needs to be upgraded to reduce the sector's energy consumption and enable the installation of new, low-carbon heating technologies such as electric heat pumps, hybrid heating systems and heat networks.

Depending on the condition of existing properties, the intervention will be moderate (e.g. installation of high-performance glazing or improvement of loft insulation) or extensive (underfloor insulation and heating or solid wall insulation cladding). For GMCA to reach its net-zero target, it needs to renovate its building stock at a rate not seen anywhere else before, achieving a rate of 400 properties per day by 2030. There is only time to upgrade every building once and it is therefore important to coordinate planning of interventions and install (for example) solar PV together with roof / loft insulation.

Along with building upgrades, innovative solutions such as Building Energy Management Systems (BEMS) can further improve building energy efficiency, reduce costs and enable participation in demand response schemes. Similarly, Buildings-to-Grid (B2G) and Vehicle-to-Grid (V2G) capabilities should be piloted and implemented to improve grid management and renewables integration. To prepare for the switch to hydrogen, properties will need to be fitted with hydrogen-ready appliances such as hydrogen-ready boilers and cookers.

The need to switch to clean energy is most urgent in the transport sector due to the air pollution that already directly affects human health. GMCA is consulting on the launch of a Clean Air Zone which would introduce charges for the most polluting commercial vehicles from 2021 and bring nitrogen oxide levels within legal limits. Furthermore, the GMCA has ambitious plans to enable and encourage a behavioural switch to sustainable modes of transport: walking, cycling and public transport. Light road transport (passenger cars, light commercial vehicles and buses) is expected to be mostly electrified but charging infrastructure is a key enabler for electric vehicle uptake –GMCA needs to drive the development of enough public EV chargers and bus charging depots.

The decarbonisation of heavy goods vehicles is currently difficult to predict and plan for given multiple competing technologies and insufficient infrastructure at the national level. As transport companies establish their vehicle preferences, local authorities need to engage with them to ensure refuelling / charging infrastructure is in place for a swift fleet replacement before 2038.

Industrial decarbonisation will differ depending on sector and industrial process. Through feasibility studies, GM's industrial producers will have to make choices to decarbonise their specific activities. Ideally, assessments will be carried out for industrial clusters to maximise decarbonisation synergies and economies of scale. GM's local authorities should assist this industrial strategy process, e.g. by providing guidance on the long-term planning of energy infrastructure.

Currently dependent on natural gas, industry will have to either electrify its processes or switch to hydrogen as the HyNet hydrogen network is expanded to GM (initially Trafford Park). To prepare for the conversion to hydrogen, manufacturing facilities will have to ensure their equipment is hydrogen-ready and collaborate with the gas network operator and GMCA to ensure a safe and timely switch to hydrogen. Where industrial emissions cannot be completely eliminated, carbon will need to be captured and either utilised for industrial purposes or sequestered.

Securing low-carbon energy supply

By 2038, electricity demand will increase to 18.7TWh accounting for 49% of energy demand. To the extent that this is technically and economically possible, GMCA should strive to meet that demand through locally generated renewable electricity. Local authorities should incentivise the installation of rooftop solar PV, as well as investment in wind farms, energy-from-waste and biomass plants. Along with growing intermittent generation, the role of storage and demand response will increase in importance – these technologies will enable self-generation optimisation and new revenue streams for metered users. To complement growing flexible capacity, Local Energy Markets, operated by commercial aggregators, local sustainable energy companies or cooperatives should be trialled and developed to spread these benefits and further improve grid flexibility.

As demand is increasingly electrified, the grid will operate closer to its nominal design capacity which will necessitate on-going grid reinforcement, as well as improved low voltage grid monitoring capabilities. In the longer-term, the need for grid flexibility, beyond that provided by behind-the-meter technologies, will be met through grid-connected smart solutions, owned and operated by energy market participants.

As a replacement for natural gas, hydrogen is expected to be a key enabler of the energy transition in GM and will account for 14TWh or 36% of total energy demand by 2038. The HyNet project in Cheshire is in advanced stages of planning and is expected to commence the production of blue hydrogen[5] in 2025. This is highly dependent upon Government supporting hydrogen with appropriate policies for CCUS and production. As production is ramped up, the hydrogen distribution network will be extended to GM where hydrogen will initially be delivered to industrial areas. Green hydrogen production will become a material alternative in the 2030s, as production is scaled up on the back of growing generation of low-cost renewable electricity from offshore wind in the Morecambe Bay.

As hydrogen supplies to GM increase, the gas grid network will have to be converted section-by-section to 100% hydrogen. Careful planning and coordination among Cadent Gas, GMCA and consumers is required to ensure a timely and safe switch to hydrogen. As the role of hydrogen increases, storage capacities will have to be developed: initially at small-scale located near industrial anchor users, and then at large-scale in salt caverns located near GM. In the long-term, GM is expected to become part of a larger North England hydrogen zone which will connect multiple hydrogen clusters, increasing access to multiple hydrogen production and storage options.

Whilst the net-zero pathway illustrates a seamless transition until 2038, there are several important risks that may impact the timing and form of the implementation. It is important to recognise these challenges up-front and understand how they can be best mitigated. Some of the key risks to consider

[5] Hydrogen produced through auto-thermal reforming of natural gas combined with carbon capture and storage

are the lack of or inadequate national policy for decarbonisation, delayed or insufficient building stock upgrades, delays to the HyNet project and delayed or limited local renewable electricity generation.

1. PURPOSE AND OBJECTIVES OF THIS WORK

Greater Manchester Combined Authority (GMCA) has set itself an ambitious target of becoming fully decarbonised by 2038, 12 years ahead of the national target of 2050. This goal creates a set of specific challenges and opportunities for the region that need to be tackled with urgency to create the desired sustainable, resilient and equitable urban region for its residents and businesses and position itself as the innovation lighthouse and economic powerhouse of the North-West.

GMCA, as the governing body for the 10 districts making up Greater Manchester (GM), has invested substantially in research and strategy development before embarking on this journey. The paper *Quantifying the implications of the Paris Agreement for Greater Manchester* from the Tyndall Centre for Climate Change Research serves as the scientific underpinning for GMCA's decarbonisation ambitions based on carbon budgets derived from Science-Based Targets.

Other key reports that reflect this rigor include *Greater Manchester's Plan for Homes, Jobs and the Environment*, *Greater Manchester's Spatial Energy Plan*, *Decarbonising Greater Manchester's Buildings*, the *5 Year Environmental Plan for Greater Manchester 2019-2024*, *Greater Manchester low-emission strategy* and the *Greater Manchester Local Industry Strategy.*

These reports each provide valuable data and insights for developing and executing a strategy towards a carbon neutral Greater Manchester but were published in different years, are underpinned by different data sets and span different time periods, which makes distilling a coherent, actionable view on decarbonisation non-trivial.

Additionally, important and relevant work has been undertaken at the regional and national level too, which includes Cadent's *Developing networks for the future*, ENWL's *Distribution Future Electricity Scenarios*, National Grid's *Future Energy Scenarios* and ENA's *Pathways to Net Zero* reports.

As key stakeholders, operators of critical energy infrastructure and knowledge partners for GMCA, Cadent Gas and ENWL wish to contribute to GMCA's ambitions. To this end, they have asked Navigant to develop a pathway rooted in the Balanced Scenario from the aforementioned ENA report and develop a pathway for GMCA to achieve this scenario.

The scenario and pathway combine national and local data and insights into a unified view on what is required for GM to reach its target. The pathway contains seven priority actions for GMCA and its key stakeholders that, when executed successfully in a timely manner, can put GM on a path to a carbon-free future by 2038.

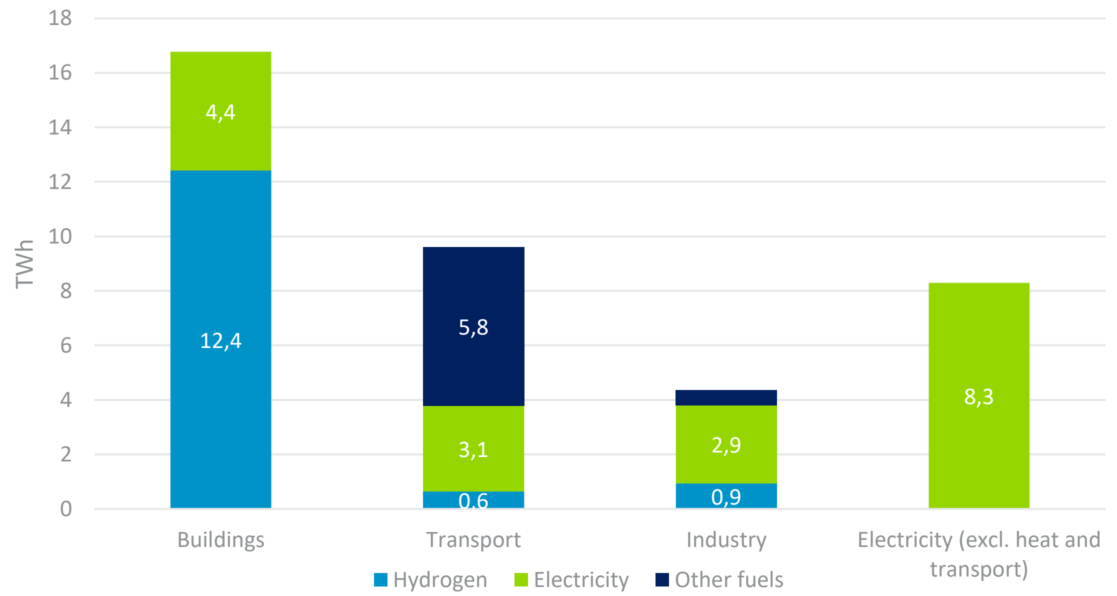
In Section 2 of this report we describe the regional Balanced Scenario and what needs to be delivered in terms of change to achieve it. Section 3 outlines the specific actions that need to be taken for successive five-year periods. Section 4, finally, discusses challenges for achieving the pathway and associated mitigative measures.

2. A BALANCED SCENARIO FOR GREATER MANCHESTER

The 2038 scenario for Greater Manchester (GM) is based on the Balanced Scenario from the *Pathways to Net-Zero: Decarbonising the Gas Networks in Great Britain*[6] study prepared by Navigant for Energy Networks Association (ENA). The Balanced Scenario, in which low carbon and renewable gases are used in a balanced combination with renewable electricity, was recommended as the most cost-optimal way to decarbonise the GB energy system. A comparison with the Electrified Scenario (in which the use of low carbon and renewable gases was minimised) revealed that total system costs of the Balanced Scenario would be lower by £13bn per year. Following the recommendation in Navigant's ENA report, the GM scenario models a 2038 energy system that is fully decarbonised through the balanced use of renewable electricity and low-carbon hydrogen.

2.1 A Balanced Scenario for 2038

The 2038 energy demand analysis indicates that GM will consume 39TWh of energy, split across buildings (17.0TWh), transport (9.6TWh), industry (4.4TWh) and electricity (excl. heat and transport) (8.3TWh). The relative share of domestic heating in total energy demand highlights the importance of improving energy efficiency in the building stock.



Note: "Other fuels" includes 5.4TWh biokerosene for aviation, 0.4TWh biomethane in heavy goods tranport and 0.5TWh biomass in industry.

Figure 4: 2038 Greater Manchester energy demand, by sector

In terms of fuels, electricity will become the most important energy carrier, as it gains importance in buildings and dominates the transport sector. Hydrogen will replace natural gas as the dominant source of heat for GM's building stock. Significant demand for other fuels is expected, in particular 5.8TWh of biojet fuel for aviation at Manchester Airport. Aviation fuel is included in the transport assessment in the above chart for completeness but is omitted in the decarbonization pathway as it is formally excluded from Greater Manchester's carbon budget.

[6] Navigant Consulting. *Pathways to Net-Zero: Decarbonising the Gas Networks in Great Britain*. Available at: https://www.energynetworks.org/assets/files/gas/Navigant%20Pathways%20to%20Net-Zero.pdf

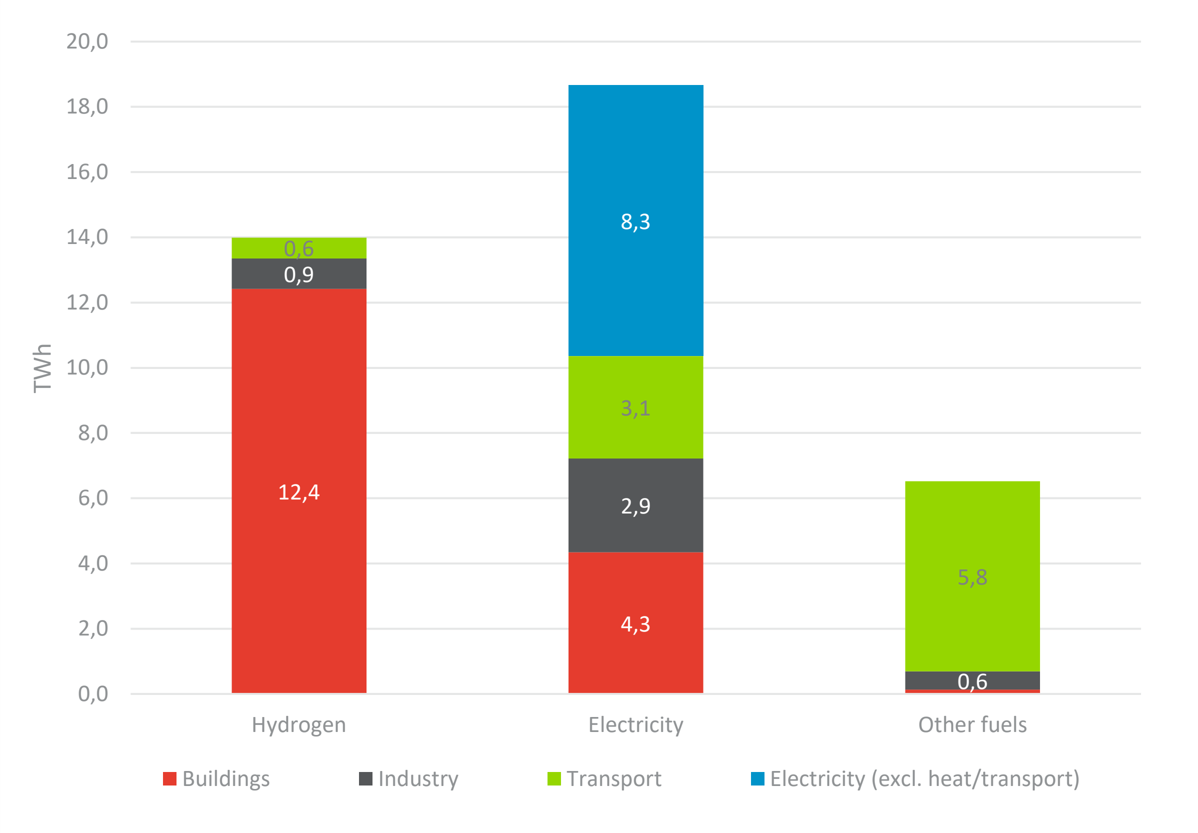


Figure 5: 2038 Greater Manchester energy demand, by energy carrier

To meet energy demand, GM will need to import the bulk of its energy, both hydrogen and electricity in our balanced scenario for 2038. 12TWh of blue hydrogen are expected to be imported from the HyNet zone, complemented by 2TWh of regionally produced green hydrogen which is expected to become available by 2038. An estimated 2TWh of electricity can be produced locally but the remaining 16.7TWh will be imported from the National Grid. Carrington power station has the capacity to generate around 7.2TWh of electricity which will be connected to the National Grid so for purposes of carbon accounting will be considered as grid electricity (with the same average carbon intensity).

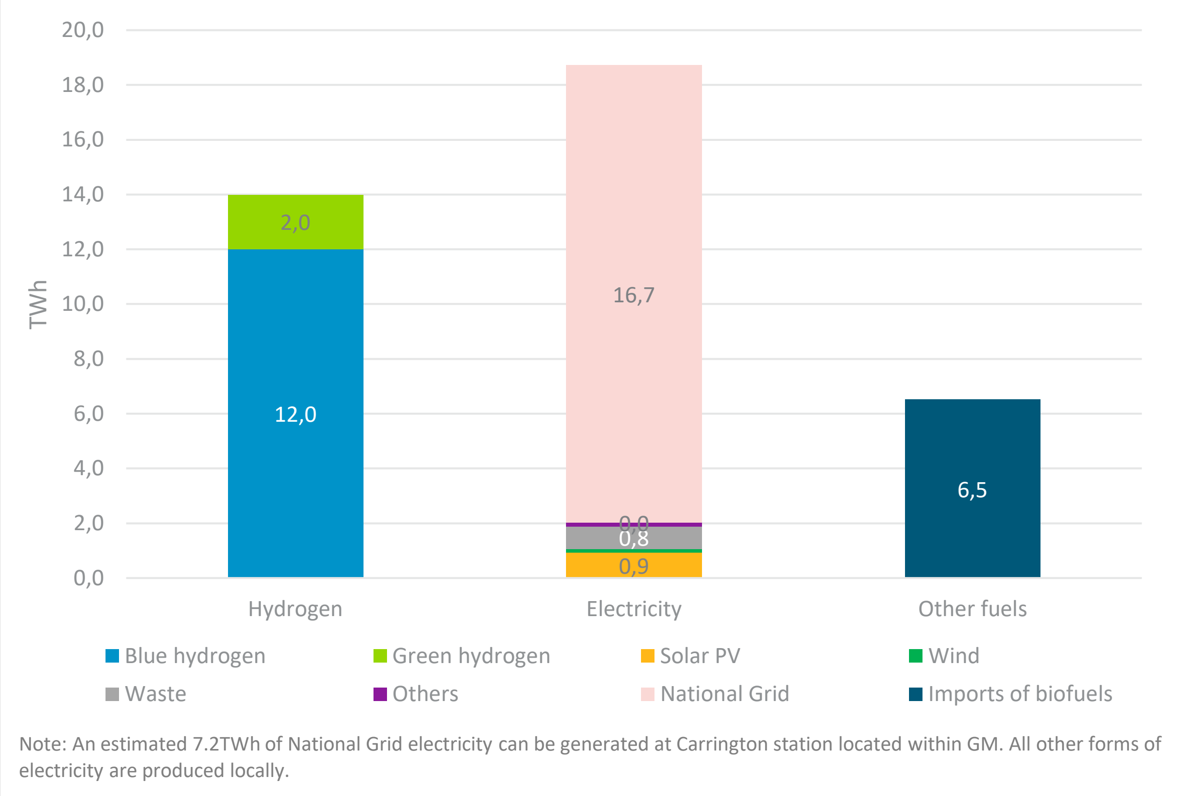


Figure 6: 2038 Greater Manchester Energy Supply

Although imported hydrogen can be considered as low carbon when generated as blue hydrogen from methane with CCS[7], or zero carbon and emission free as green hydrogen from (excess) renewable energy, the same cannot be assumed for imported electricity. The expected 2038 carbon intensity levels for 2038 grid electricity range from 13gCO_2/kWh to 74gCO_2/kWh in National Grid's Future Energy Scenarios. To mitigate this while keeping to the 2038 local net-zero target, several actions can be undertaken:

- Stimulate local renewable generation, although this is not expected to be able to fully fill the gap, given the stated potential for solar PV, wind and biomass in the region.
- Stimulate local residents and businesses to switch to a green supplier, which would enable GM to claim their electricity consumption as carbon-free, provided there is a monitoring system in place that enables GMCA to evidence the uptake. In the longer term, the increased demand for renewable electricity would increase supply and GMCA would thus contribute to decarbonising the national grid.
- Lobby at the national level to accelerate the decarbonisation of the National Grid beyond what is currently foreseen in National Grid's Future Energy Scenarios
- A final option, under the assumption that there is no constraint for hydrogen supply, is to reduce electricity consumption in favour of greater hydrogen use.
    - A larger share of the building stock could be converted to hydrogen boilers instead of hybrid heat pumps;

[7] Auto-thermal reforming with CCS capture rate circa 93%.

- Electrification of low-temperature heat industry could be de-emphasised in favour of hydrogen-based solutions;
- Decarbonisation of rail transport could be prioritised over electrification.

- A final option would be to significantly increase the use of Bio-energy with carbon capture and storage (BECCS) well beyond that required to simply offset the CO_2 produced from HyNet's blue-hydrogen production.

2.2 Evolution of energy demand in Greater Manchester

Figure 7 shows how dramatically GM's energy landscape will change between 2018 and 2038. Total energy demand is expected to fall from 52TWh to 39TWh on the back of energy efficiency improvements and despite a growing population and economy. The building sector will become the dominant consumer of energy increasing its share from 36% (18.9TWh) in 2018 to 43% (16.8TWh) in 2038, whilst the share of the transport sector is expected to decline from 35% (18.1TWh) to 25% (9.7TWh).

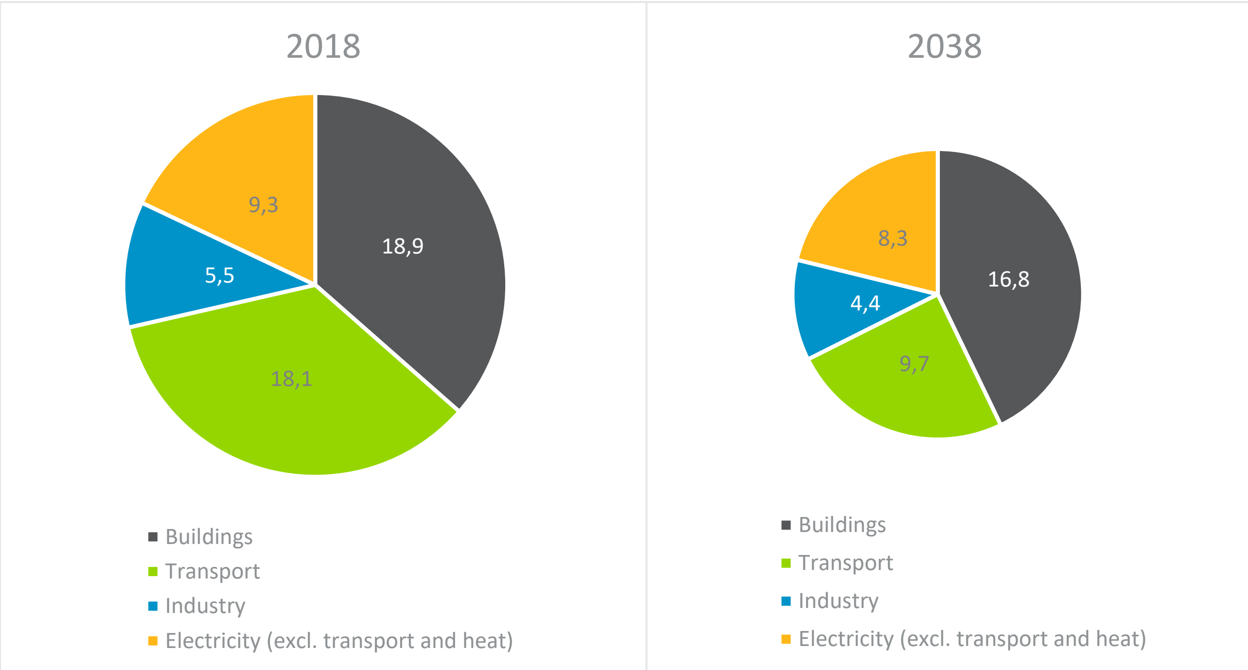


Figure 7: Energy demand in Greater Manchester in 2018 and 2038 [TWh]

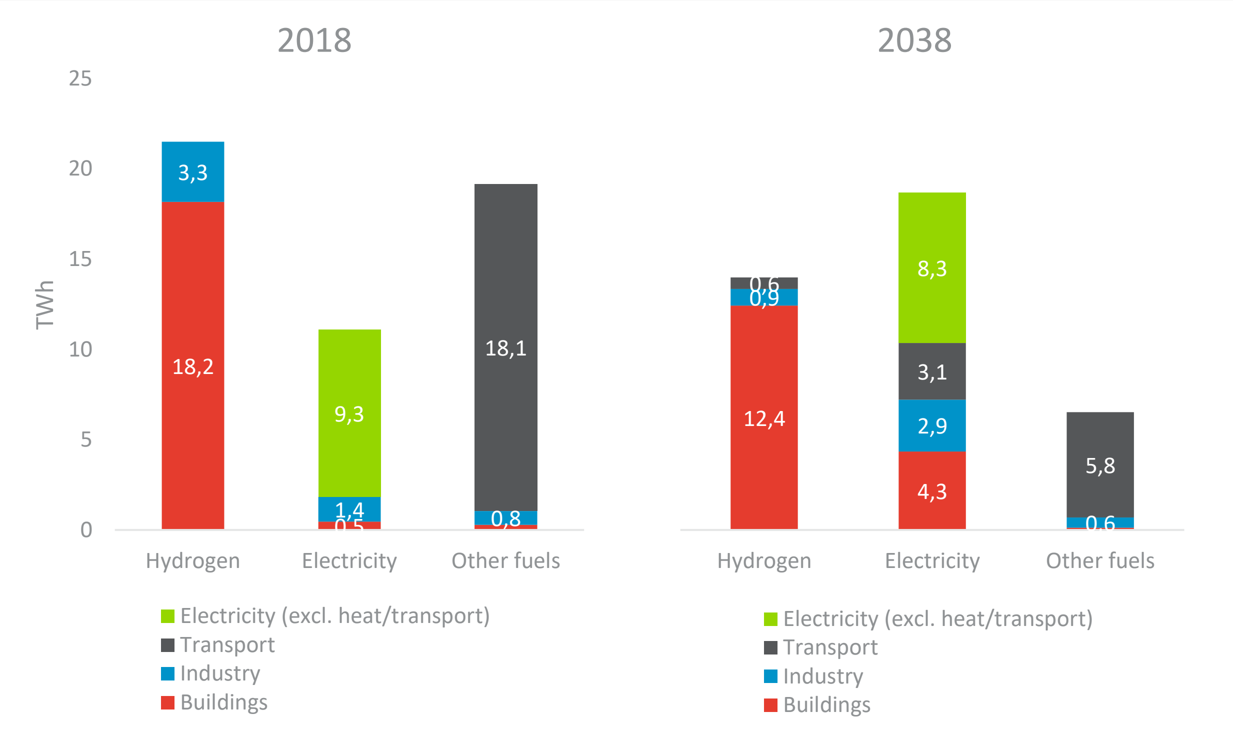


Figure 8: Evolution of energy demand, by sector and fuel, 2018 and 2038

To meet the 2038 net zero target, GM's energy mix will have to undergo dramatic transformation over the next 18 years. Fossil fuels like oil and natural gas will gradually be phased out in favour of low-carbon fuels. Blue hydrogen is expected to grow from around 2026 when the HyNet zone reaches the GM region. With time, the carbon intensity of electricity will decline on the back of growing local generation, as well as increasing renewable penetration in the National Grid. The changing energy mix, as well as, declining carbon intensity of electricity is depicted in Figure 9.

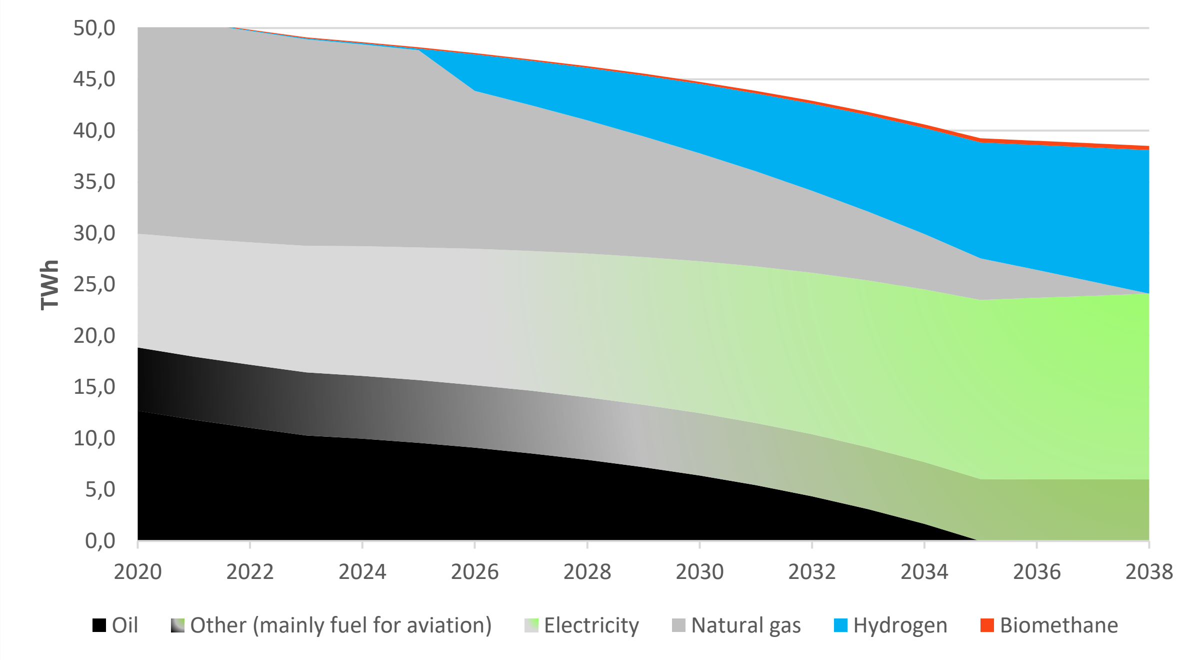


Figure 9: Evolution of energy consumption in Greater Manchester[8]

2.3 Buildings / Heat

As 96% of buildings in GM are connected to the gas grid, the city-region heavily depends on natural gas burnt in gas boilers for space and water heating. The decarbonisation of buildings will lead to a much more diverse mix of heating technologies in the future. The transformation of heating technology will depend on the energy efficiency of the building stock and spatial and technical capacity to accommodate new heating installations (see appendix B for modelling details). By 2038, we expect 47% of residential properties will be heated with a hybrid heating system[9], 34% will be heated with a hydrogen boiler, 15% will use all-electric heat pumps and 4% will be connected to a heat network. The commercial sector is expected to see a larger uptake of hybrid heating systems which in 2038 will heat 74% of commercial buildings, followed by 16% of properties heated with hydrogen boilers and 10% using all-electric heat pumps.

[8] The chart covers energy consumed in the three key demand sectors: buildings, transport and industry. "Oil" refers to oil products used in road transport, i.e. petrol for different types of vehicles; "other" mainly consists of fuel for aviation (kerosene or bio-kerosene) and secondary fuels in industry (e.g. biomass); "electricity" includes distributed and grid electricity (the carbon intensity of which declines with time); "natural gas" refers to consumption of methane in buildings and industry; "hydrogen" refers to consumption of hydrogen in buildings and industry; "biomethane" refers to biomethane consumed in transport as bio-CNG or bio-LNG.

[9] A hybrid heat system combines an electric heat pump with a low carbon gas fired boiler. For Greater Manchester the low carbon gas will be hydrogen.

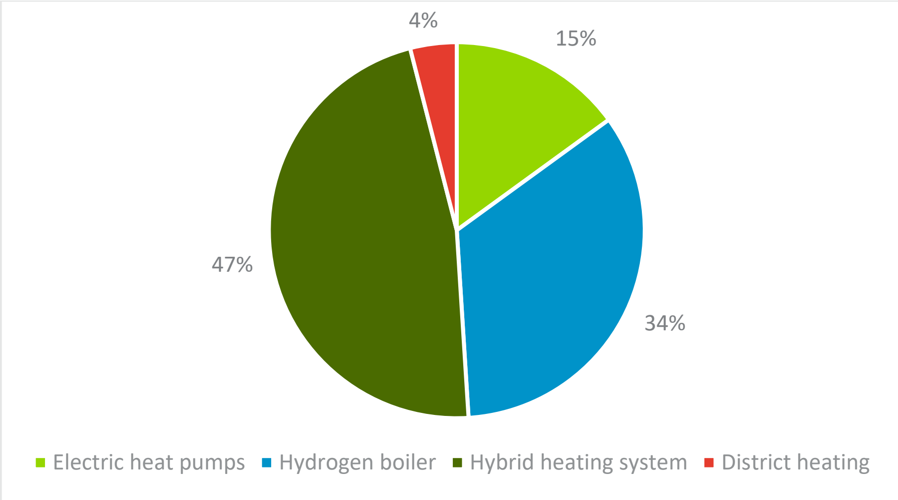


Figure 10: 2038 Residential Heating Technology Mix for Greater Manchester

Figure above shows the technology mix for all of GM, but as the building stock is not uniform across its 10 districts, in terms of age, size and type, differences in the technology mix will exist, as is shown in Figure . Districts with relatively new building stock or a high proportion of planned new builds, such as Manchester, Salford, Trafford and Wigan will see a relatively higher share of district heating and all-electric solutions. Districts with older, more difficult to upgrade properties like Tameside can expect a proportionally higher number of buildings to use hydrogen boilers by 2038.

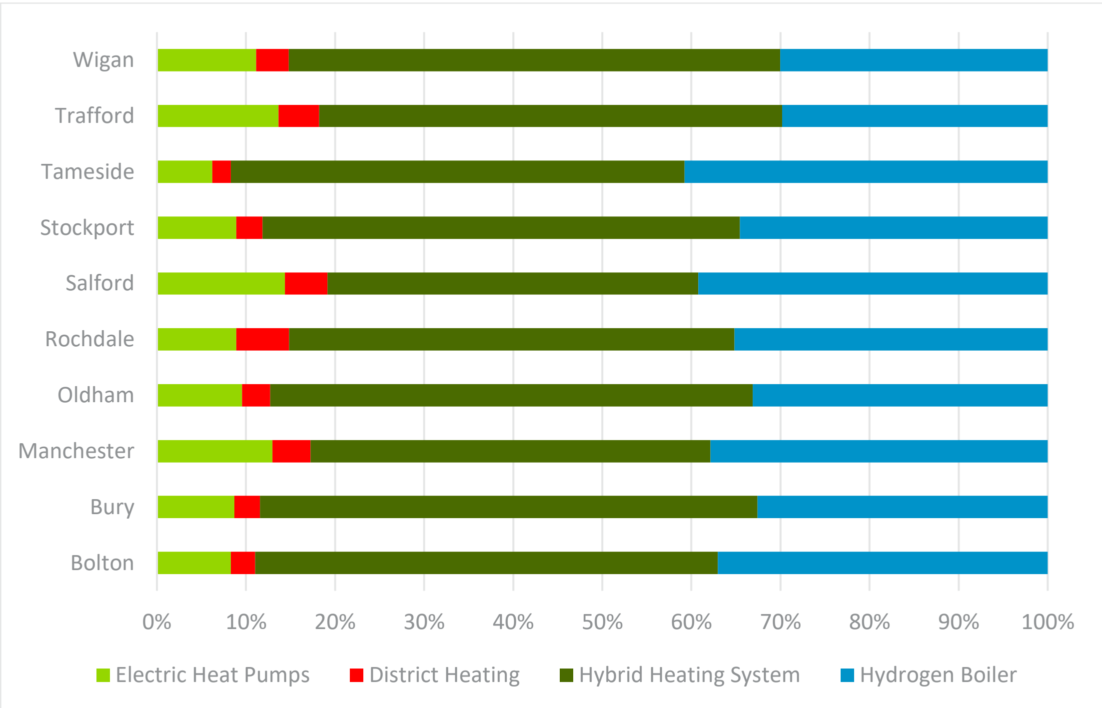


Figure 11: 2038 Heating technology mix per district

The installation of heat pumps and hybrid heating systems requires comprehensive improvements in the energy efficiency of buildings in GM. For the majority of existing buildings, installing hybrid heating systems is expected to require moderate renovation, e.g. install high-performance glazing or improve loft insulation. These “moderate” interventions are expected to yield a 21% reduction in energy consumption. Existing buildings switching to fully electric heat pumps will have to undergo retrofitting that brings them to an A rating which will involve extensive retrofitting, e.g. underfloor insulation and heating or solid wall insulation cladding. Such “extensive” building interventions are expected to result in a 54% reduction of energy consumption for space heating and hot water. More extensive retrofitting does of course come at higher cost, so from an economic perspective there will be trade-offs between the overall affordability of green gas, hybrid and full electric heating solutions.

At the same time, the new heating technologies that will dominate building heating are more fuel efficient compared to gas boilers used today. On average, we expect a heat pump to use 60% less energy than a conventional gas boiler and a hybrid heating system to use 19% less energy. Brought together, the expected building improvements and more efficient heating result in lower overall energy demand for heating of the existing building stock. The decline is slightly offset by increased building space: the number of residential homes is expected to grow by 200[10]227, whilst commercial space will expand by 2.9m m^2. As a result, overall energy demand for building heating declines from 19TWh in 2018 to 16.8TWh in 2038. Figure 12 depicts the fundamental change of heating fuel from natural gas which provides 96% of the energy today. The 2038 picture is very different as heat will come from hydrogen and electricity, accounting for 74% and 26% of the energy demand respectively.

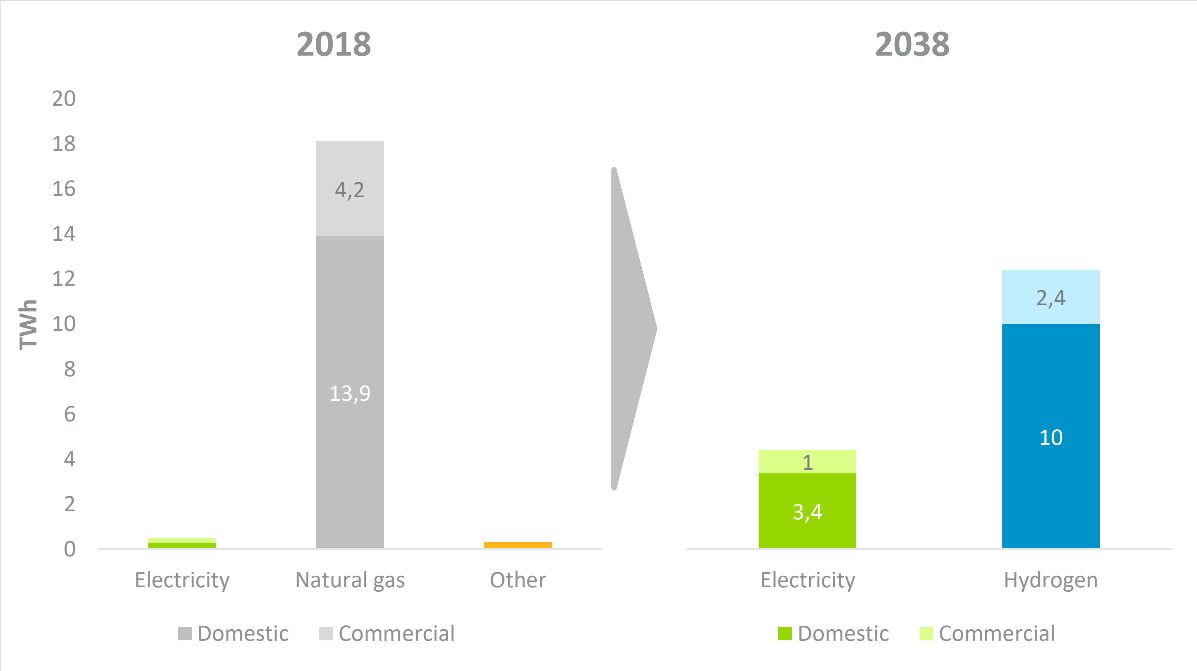


Figure 12: Evolution of energy demand in the GM building sector

2.4 Transport

GM aims to rapidly decarbonise its road transport through a switch to zero-carbon transport modes – the *Transport 2040*[11] strategy sets out a 2035 target for all cars and buses to be zero-emission. As the city-region grows, the authorities aim to reduce road traffic and mitigate air pollution by incentivising the use of sustainable transport modes like public transport, cycling and walking. The share of daily journeys taken by car is expected to fall in favour of sustainable travel from 61% currently to 50% in 2040.

Given expected cost declines and national and local policies, we expect that 96% passenger cars in GM will be electric by 2038 and 4% will be fuel cell vehicles (mainly SUVs), most buses (85%) will be electric and a smaller share (15%) will run on hydrogen, similarly light commercial vehicles (LCVs) expected to be mainly electric (90%) with a smaller share powered by hydrogen fuel cells (10%). Heavy goods vehicles (HGVs) will see the most varied mix of fuels: 50% will run on hydrogen, 30%

[10] Greater Manchester Spatial Energy Plan. Available at: https://www.greatermanchester-ca.gov.uk/media/1363/spatial_energy_plan_exec_summary.pdf

[11] Greater Manchester Transport Strategy 2040. Available at: https://tfgm.com/2040

will be battery-electric trucks. 20% will run on biomethane, either as BioCNG for regional routes or Bio-LNG for national / international transit.

Energy demand in road transport will undergo profound transformation as seen in figure 13. Overall demand will fall from 12.7TWh in 2018 to below 4.2TWh in 2038 due to the high fuel efficiency of zero-emission transport. For instance, a battery-electric vehicle consumes around 70% less energy compared to the amount of petrol / diesel a conventional car when compared in kWh terms. A bus or truck powered by hydrogen fuel cells uses around half the amount of energy compared to its diesel-powered equivalent.[12] In terms of specific fuels, 12.6TWh of oil demand is expected to be replaced by 3TWh of electricity and 0.8TWh of hydrogen demand. The transport sector is one of the key growth areas for electricity in GM, as well as the industrial sector.

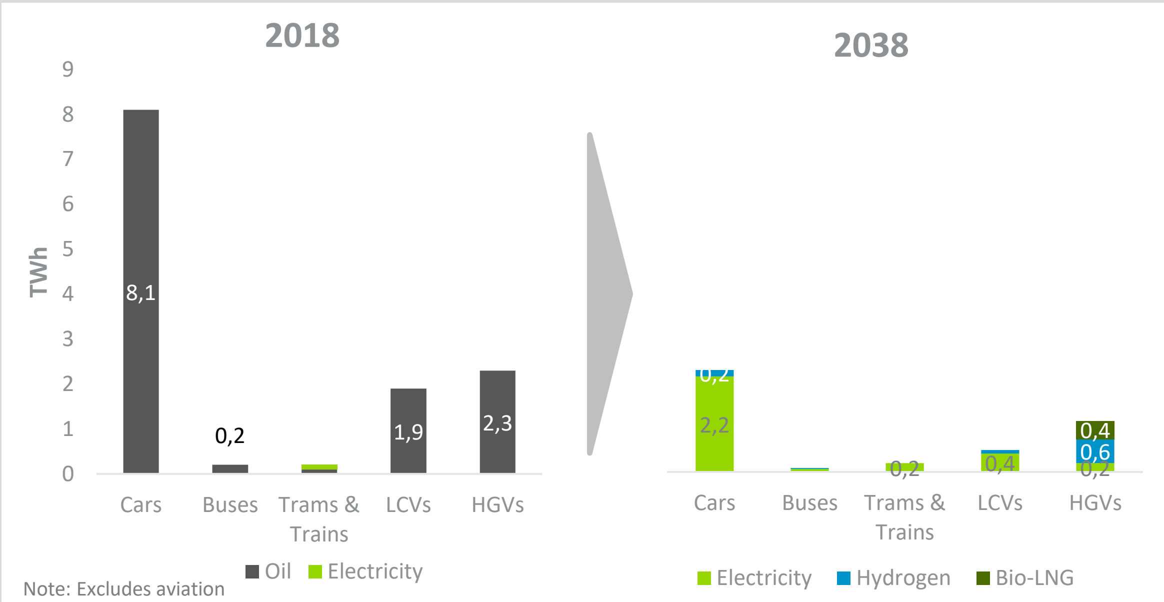


Figure 13: Evolution of energy demand in the GM road transport sector

2.5 Industry

Energy demand in industry is used for heat production and powering electric appliances. This section covers heat-related use of energy, whilst electricity demand for non-heat-related activities is included in section "2.4 Electricity (excl. heat or transport)". Compared to neighbouring cities and regions like Cheshire or Liverpool, industry in GM is relatively non-energy-intensive, dominated by industries like food processing, textiles, paper and fast-moving consumer goods (FMCG) manufacturing. Accordingly, energy is mostly used in low temperature processes which currently account for roughly 53% of energy demand, followed by high temperature processes (31%) and space heating (16%). In fuel terms, the key energy source in each type of end-use today is natural gas which accounts for 61% of energy used for heat-related activities in industry. The equivalent share for electricity is 25%, whilst other fuels like oil, coal and biomass constitute the remaining 14% of demand.

Decarbonising industry is highly sector-specific, and the cost and complexity associated with changing industrial processes will vary depending on their nature. The cost of switching to electricity or hydrogen will be subject to technology costs, as well as the relative cost of electricity and hydrogen. A detailed assessment of each individual sector and economic analysis of costs is required to give a detailed outlook for industrial decarbonisation. In principle, the electrification of low

[12] For assumptions on low-carbon fuel consumption and mileage please see Table 71 of Navigant's *Gas for Climate* study available here: https://gasforclimate2050.eu/wp-content/uploads/2020/03/Navigant-Gas-for-Climate-The-optimal-role-for-gas-in-a-net-zero-emissions-energy-system-March-2019.pdf

temperature processes is considered feasible and the analysis assumes that natural gas will be replaced by electricity in the future. Electrifying high temperature processes is challenging given the technical requirements of these processes, the large amount of electricity that would be required and the associated cost. Instead, natural gas used in these processes is expected to be replaced by hydrogen which, as a low-carbon gas, has similar energy properties and can also be used in CHP installations to produce both electricity and heat. In a similar way to commercial buildings, where gas boilers are used for industrial space heating, these will be replaced by hydrogen boilers and hybrid heating systems.

As industrial processes are enhanced and become more energy-efficient, industrial energy demand is expected to fall with time. The decline driven by energy efficiency is partially offset by the expansion of industrial space, which is expected to grow by 4.75million m^2 adding 0.57TWh of new electric demand for space heating. As depicted in figure 14, energy demand for industrial heat in GM falls from 5.45TWh in 2018 to 4.36TWh in 2038. Electricity is expected to provide 66% of this energy, followed by hydrogen (21%) and other fuels (13%) like biomass.

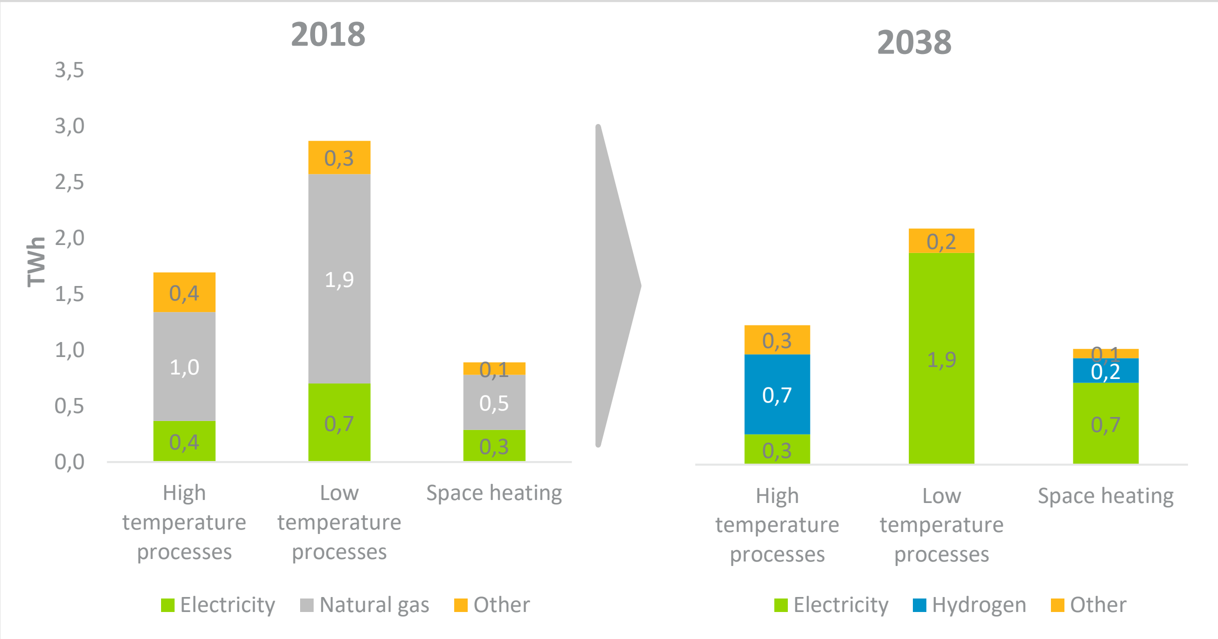


Figure 14: Evolution of energy demand in the GM industry sector

2.6 Electricity (excl. heat or transport)

Transport and heating for buildings and industry are two areas where demand for electricity is expected to increase rapidly in the future. However, demand for electricity today is dominated by other uses such as lighting, powering electrical appliances, air conditioning, etc. Current demand for electricity (excl. heat and transport) in GM is around 9.3TWh, of which 5.3TWh is used by industrial and commercial consumers and 4TWh by domestic users.

Since 2009, demand for grid electricity has been falling because of gradual improvements in energy efficiency and consumers' own generation. This trend is expected to continue as decarbonisation policies incentivise energy conservation and distributed generation. On the current trend, demand for electricity in GM, excluding heat and transport demand, will fall by 10% to 8.3TWh by 2038.

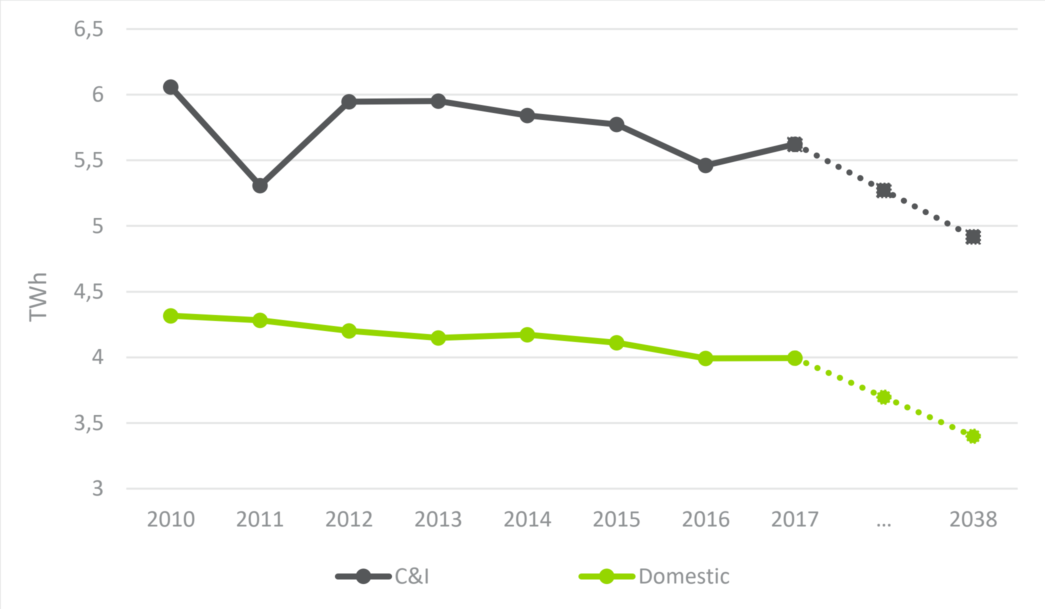


Figure 15: Electricity (excl. heat and transport) demand in Greater Manchester. Source: BEIS

2.7 Hydrogen supply for Greater Manchester

The transition from natural gas to hydrogen will require a secure supply of low-cost hydrogen, which can match growing demand over time. GM is favourably located in what will become a North-West hydrogen zone which will grow out of the HyNet project located in Cheshire.

The HyNet project expects hydrogen production[13] to start as soon as 2025 and be delivered to GM by 2026. According to the companies developing HyNet, production can be ramped up from an initial 3TWh in 2025 to 50TWh by 2035. Crucially, the project's developers believe production can be accelerated to meet demand growth and that the long-term quantities required by GM are manageable as there are no significant resource or technical constraints for hydrogen production to meet the expected regional demand. Liverpool Bay has extensive capacity for CO_2 sequestration, whilst available salt caverns provide a relatively low-cost and effective way of storing hydrogen.

As the cost of electrolysis declines, green hydrogen will become an alternative source of zero-carbon hydrogen. Expanding offshore wind capacity in the Morecambe Bay will provide large quantities of low-cost, renewable electricity. Excess production can be used as a near-zero-cost fuel for electrolysis to produce green hydrogen for the North West. We estimate there will be up to 11TWh of green hydrogen in the North of England – on a pro-rata basis this would mean 2TWh could be used in GM.

[13] HyNet will produce hydrogen by auto-thermal reforming (ATR) at the Stanlow refinery with 93% CO2 capture rate – "blue hydrogen". To be net-zero such blue hydrogen will need to be supplemented with bioenergy combined with CCS (BECCS). BECCS can be used to generate negative emissions, offsetting the 7% of CO2 not captured in the ATR process. Alternatively, blue hydrogen can be net-zero if around 10% of the feed gas is biomethane.

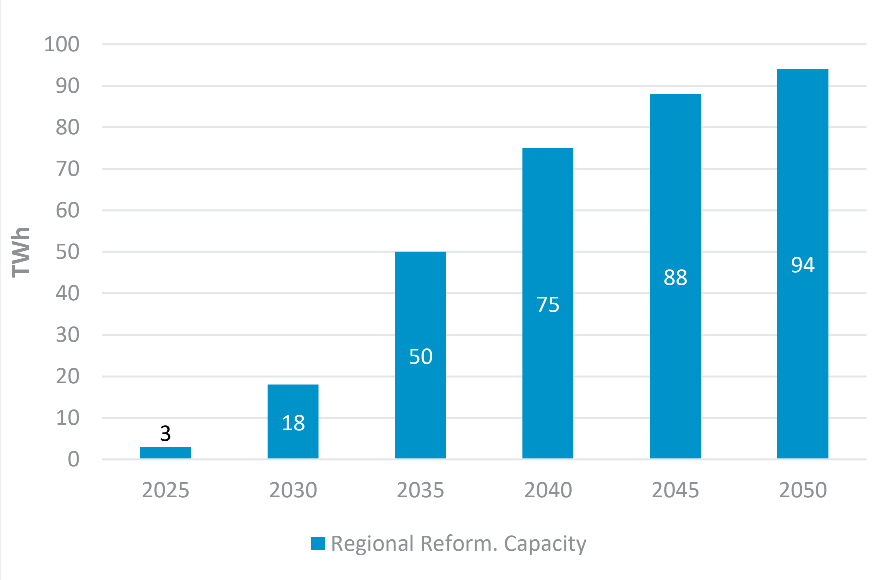


Figure 16: Regional blue hydrogen production capacity

Source: HyNet Low Carbon Hydrogen Plant Report for BEIS

2.8 Electricity supply for Greater Manchester

The simplest option for securing zero-carbon electricity is to produce it locally. In the long-term, GM should utilise its full potential to produce renewable electricity locally where this is cost-effective. According to the GM Spatial Energy Plan[14], there is technical potential to generate 917GWh of solar power, 143GWh of wind and 4.4GWh of hydro power in the GM region. In case technical potential is currently underestimated, local authorities should strive to increase local renewable generation beyond this level.

Local authorities are pro-actively encouraging the growth of local renewable electricity - the GMCA's 5-Year Environment Plan[15] plans for the addition of 45MW of solar PV by 2024. This will bring total installed solar PV capacity to 190MW – still a long-way from the 682MW which have been deemed technically feasible. To achieve this scale of solar PV capacity around 7500 residential (4kW) solar PV systems need to be installed annually until 2038.

Waste is another biofuel source which should be utilised to its maximum potential. GM currently produces around 200GWh through anaerobic digestion, sewage and landfill gas. Going forward, energy from waste (EfW) is expected to come from developing technologies such as Advanced Conversion Technologies (ACT) and new anaerobic digestion capacity. According to National Grid's Future Energy Scenarios[16], GM could have 138MW of EfW capacity installed, producing up to 830GWh of electricity in 2038. To increase energy-from-waste production above the national average, local authorities could increase the amount of capacity that is installed within GM.

As seen in Figure 17, around 2TWh of renewable electricity is expected to be produced in GM by 2038, stemming from two key sources: solar PV and waste. This is a "best estimate" scenario but production could be increased, as discussed above, if additional measures to incentivize renewable electricity are put in place by the local authorities.

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[14] Energy Technologies Institute. *Greater Manchester Spatial Energy Plan*. Available at: https://www.greatermanchester-ca.gov.uk/media/1277/spatial-energy-plan-nov-2016.pdf

[15] GMCA. *5-Year Environment Plan for Greater Manchester 2019-2024*. Available at: https://www.greatermanchester-ca.gov.uk/media/1986/5-year-plan-branded_3.pdf

[16] National Grid. *Future Energy Scenarios 2019*. Available at: https://www.nationalgrideso.com/future-energy/future-energy-scenarios-fes

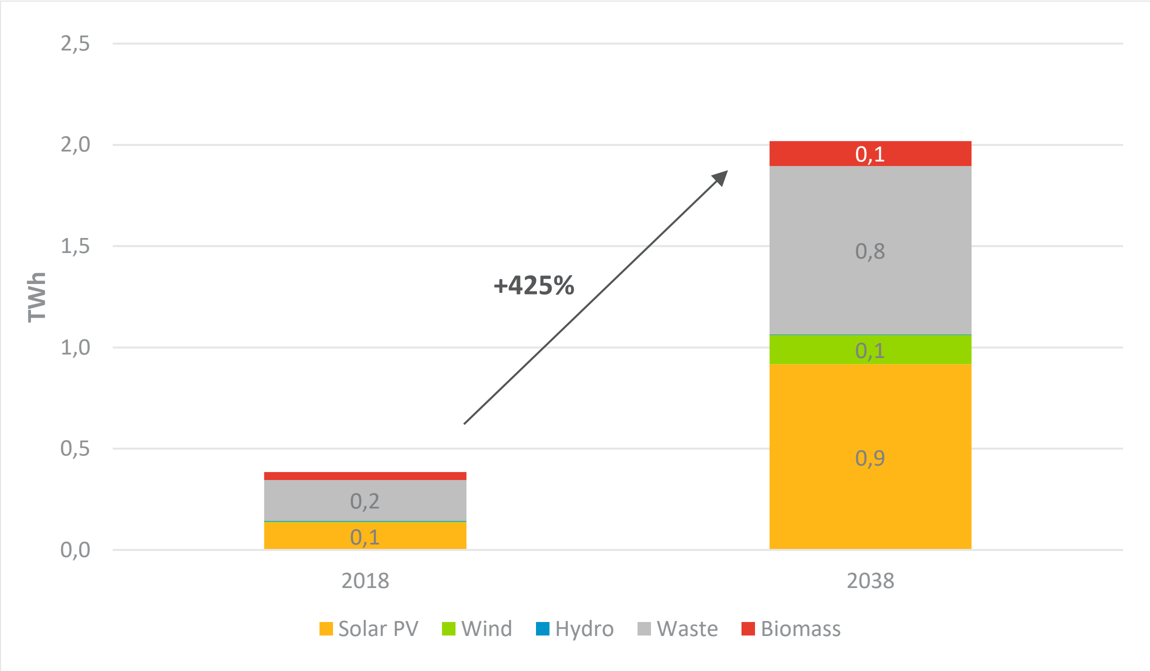


Figure 17: Evolution of renewable electricity generation in Greater Manchester

3. A PATHWAY TO A DECARBONISED GREATER MANCHESTER

We have developed a pathway, or high-level implementation plan, to deliver the 2038 Balanced Scenario for Greater Manchester (GM). The pathway is informed by our scenario analysis, stakeholder consultation and developed in a qualitative way. It builds on our work performed for ENA, existing work from, and commissioned by, GMCA and work undertaken by Cadent and ENWL that informs their RIIO-2 business plans.

The pathway is developed along three main tracks, *Kickstarting the transition*, *Transforming the demand base* and *Securing low-carbon supply* and maps elements that consist of groups of related actions to 5-year blocks, reflecting typical planning cycles and regulatory periods.

Figure 18 shows a high-level overview of the pathway and seven priority actions. A full-page version of this graphic can be found in Appendix C.

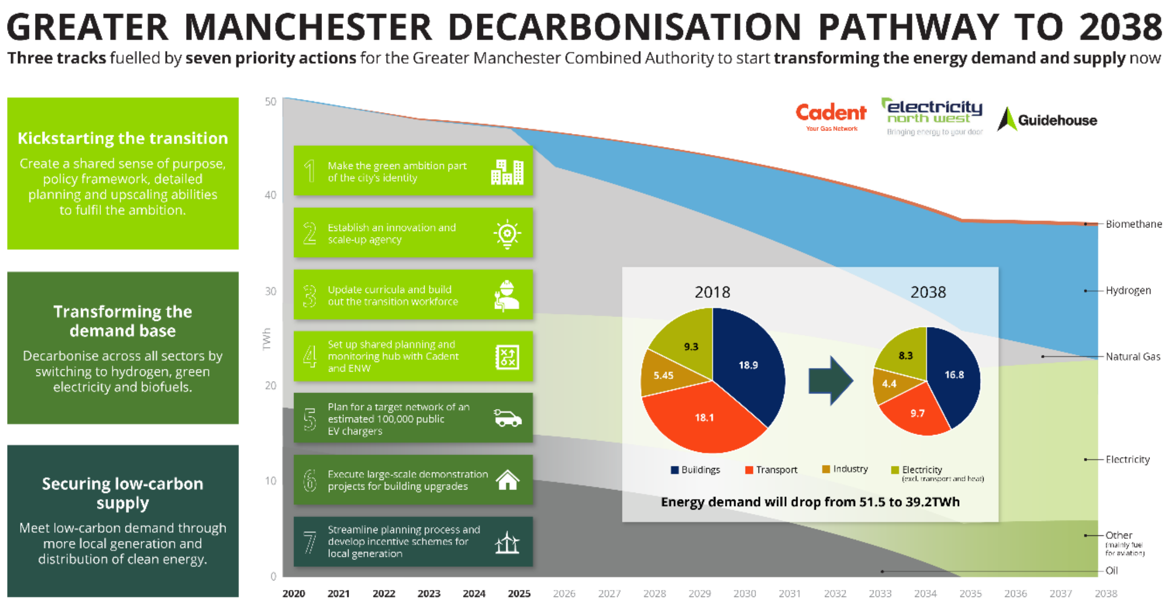


Figure 18: Infographic introducing the decarbonisation pathway for Greater Manchester.

In the remainder of this section we elaborate the pathway tracks introduced above. Each track is characterised by three to five elements that together help to achieve the track's goal. These are briefly introduced at the start of each section. Key actions are coloured according to the time period they refer to:

Furthermore, we distinguish three types of actions, from the perspective of GMCA, and use icons and color-coding to indicate the level of involvement of GMCA, where higher levels of saturation indicate more involvement of GMCA, as illustrated in the legend below. Each action has a unique identifier for easy referencing that is composed of a prefix referring to the main pathway track and a sequence number.

TIME PERIOD	LEGEND for Key Actions	ID
	Decarbonisation action led by, or under the responsibility of, GMCA	ID1
	Decarbonisation action for GMCA to influence/collaborate with key stakeholders	ID2
	Decarbonisation action of key stakeholders that GMCA should monitor/be aware of	ID3

Finally, a graphical indicator is used to identify the seven priority actions that Greater Manchester Combined Authority (GMCA) needs to take in the first five-year period to put itself firmly on a path to net-zero in 2038:

3.1 Kickstarting the transition

GMCA's net-zero carbon target has the potential to fundamentally change the region, positioning it as the energy transition lighthouse of the UK. This brings benefits that go beyond those of the decarbonisation itself by creating a metropolitan region that combines exceptional liveability with economic strength and resilience.

In the first five years of our pathway, key actions need to be taken to kickstart this transition that lay the foundation for a successful transformation. The focus in this period is on mobilizing enthusiasm and creating trust, defining a clear policy framework underpinned by innovative business and financing models, capacity building of skills and resources, and moving from planning and design to implementation at scale. In subsequent years, planning efforts shift to embedding GM in the expanding national biofuel and hydrogen ecosystems.

Kickstarting the transition
Create a shared sense of purpose, policy framework, detailed planning and upscaling abilities to fulfil the ambition.

- Share the ambition
- Shape policy and trial
- Develop scalable solutions
- Build the workforce
- Plan for large-scale implementation

3.1.1 Engage with all of society to bring about change

GMCA's ambitious decarbonisation target requires the region to come together and unite behind this goal. Only when local authorities, business and residents collectively embrace the challenge and the opportunities it brings will the transition to a net-zero carbon energy system be achievable.

A clear dot on the horizon is what this net-zero carbon energy system will look like, and this is of key importance as it will help the identification of key actions, provide clarity to residents and will unlock investments from (local) business in low-carbon solutions.

To develop and keep momentum, this vision for the future should be combined with short-term goals that have tangible benefits for residents and business alike. Successes need to be celebrated early on to demonstrate progress. Creating a positive vibe around the net-zero target attracts investments and talent, stimulates skill development and strongly increases the available resource pool, all key requirements for a successful transition of the region.

GMCA should aim for sense of collective pride around its net-zero goal comparable to that of the 1960s and 1970s on Florida's Space Coast, where Kennedy's Moon-Shot united people from all walks of life around a common goal that continues to inspire 50 years later.

	Key Actions	ID
2021-2025	• GMCA should make its decarbonisation ambition an integral part of its identity, create a common sense of purpose elevating its profile as a leading, innovative and green region. To raise awareness, the GMCA should develop a communication strategy including integrated branding, urban and on-line presence which clearly sets out the vision, explains the motivation and strategy. User-friendly learning resources should be prepared explaining the climate action GM's residents and businesses can take.	K1
	• GMCA should lead by example and decarbonise its own operations to build trust in the achievability of the 2038 target.	K2

3.1.2 Shape policy and trial

Clear national policy and regulatory guidance are of key importance to achieving regional goals. Not only do they define the boundaries within which regional authorities have to operate, they also ensure a level playing field and provide clarity needed to unlock much needed investments. Such regulatory and policy frameworks for hydrogen and heat do not yet exist at the level needed by GM, which is in part a consequence of its decarbonisation target being 12 years ahead of the national target. Specific policies and regulations that are of key interest to GM include, but are not limited to:

- Gas Safety (Management) Regulations (GS(M)R) and Calculation of Thermal Energy Regulations (CoTER) influence the extent to which hydrogen can be injected into the gas networks. The Institute of Gas Engineers and Managers (IGEM) is developing new standards for network gas quality with the Health and Safety Executive (HSE) and others. The Future Billing Methodology (FBM) and Real Time Networks (RTN) are two gas network lead initiatives that will facilitate accurate customer billing with blends of hydrogen (and biomethane).

- Carbon capture and storage will need a viable commercial business model and risk allocation to underpin its development. It is likely that a Regulated Asset Base (RAB) structure will apply to transport and storage. Capture for electricity generation is likely to be a form of Contract for Difference, whilst capture for industry could follow several models. How risk of carbon storage is dealt with at the end of project life is also a significant challenge. A consultation by BEIS is ongoing.

- The commercial business to support hydrogen production (and therefore further development of the HyNet project) is also under development with BEIS. A consultation process has recently started, and this also strongly links to the CCS business model for blue hydrogen.

- Heat networks will play a small but important role in the overall decarbonisation pathway nationally and with GM. How commercial and industrial heat generators are incentivised to develop a heat network to neighbouring facilities or buildings requires a clear incentive package.

- Demand management and demand side response can reduce peak energy requirements and therefore generation capacity needs. How these mechanisms materially contribute to capacity markets will need further development.

- Financial support mechanisms will also be required for building renovation (replacing the Green Deal), installation of low carbon heating systems (a BEIS consultation has been launched in April 2020 for this) and for industrial competitiveness with decarbonisation.

These (and other) policy and regulatory issues will be set nationally by BEIS and Ofgem, but GMCA will need to influence the shape and particularly timing given its 2038 target for decarbonisation. This may require GMCA to develop its own solutions for some of these issues.

	Key Actions	ID
2021-2025	• GMCA should leverage the option of policy sandboxes where possible to generate momentum and inform future policy development, i.e. around building codes and local energy trading.	K3
	• GMCA should work closely with national stakeholders to monitor and influence the development and adoption of future-facing policy and regulation on hydrogen, CCS, heat and buildings.	K4

A key requirement of all new policy related to sustainable electricity and heat is that it will need to strike a balance between respecting customer choice, affordability, a fair sharing of costs and safeguarding implementability, while protecting vulnerable customers. This is a challenging objective and Cadent and ENW's extensive knowledge and experience in these areas should be leveraged to tailor national policy and convert it into local programs.

3.1.3 Development of scalable solutions

For a viable transition to a net-zero carbon energy system, products, services and solutions are needed that reduce costs, implementation time and invasiveness of the transition compared to what is currently on the market. Innovation is required to ensure that current nascent technologies can be rapidly matured into robust, commercially viable products and solutions that can be deployed at scale.

At least as important as technological innovations are innovative business and financing models and new propositions for end-users, to ensure that payback times of investments (e.g. sustainable heat) are within the typical event horizon of owners / occupants. As an example: heat-as-a-service or even comfort-as-a-service propositions could provide clarity to citizens on future home heating costs while providing grid operators and energy suppliers much need flexibility with respect to heating system upgrades. An example of a comparable setup that's proving to be successful is EnTranCe[17], the Energy Transition Centre in Groningen, The Netherlands where two universities, vocational schools, a renowned knowledge institute, businesses, local authorities and social institutions develop the innovations that are needed for the energy transition.

Investing now in innovation to create advanced solutions and services is not only a requirement for decarbonising GM, it also creates a first-mover advantage for GM business in regions that are on a less ambitious pathway.

	Key Action	ID
2021-2025	GMCA should collaborate with local higher educational institutions, establish an innovation and scale-up agency that helps mature mid-TRL (technology readiness level) products, services and supporting business models.	K5

3.1.4 Build the workforce

Having a sufficiently large resource pool with the right skills is a key requirement for success too. The challenge to decarbonise transport, industry, the electricity sector and the building sector in under two decades is immense. To get a sense for the effort required: if all residential buildings in GM were to

[17] https://www.en-tran-ce.org/en/over-entrance/

see an intervention of some sort, and this were to happen linearly, roughly 300 properties would need to be upgraded every day, starting today. This increases to over 400 per day if we consider that the first years are likely needed to get to the point where upgrading at scale can start. Add to that the work required to install local renewables, EV-charging infrastructure, and converting the gas grid to be hydrogen ready and from this non-exhaustive list the magnitude of the challenge becomes very tangible.

	Key Action	ID
2021-2025	GMCA should collaborate with Cadent and ENWL, vocational schools, businesses and others to update curricula and provide internships to develop the skills and resource pool required for the net-zero ambition in an accelerated timeframe. To achieve the appropriate rate of building interventions, a dedicated workforce of around 20,000 trained contractors will be required by 2025. Digitalizing workflows can help achieve the required efficiency levels and execution speed.	K6

3.1.5 Plan for large-scale implementation

In practice, lead times of 5-7 years are observed for large-scale transformational projects in the built environment. Clarity early on what interventions are needed where, when buildings will be upgraded to low carbon heating systems and what system (heat pump, hybrid heating system, hydrogen boiler or district heating) that will be installed is therefore of crucial importance for an efficient, cost-effective transition. Cadent and ENWL can provide detailed insights on current gas and electricity network capacities at the neighbourhood level, informed by planned and predicted uptake of EVs, solar PV and local hydrogen availability resulting from imports via HyNet. Additionally, building owners, developers and local authorities each hold crucial data on real-estate development plans and local energy generation plans that have important place making implications. Therefore, integrated whole of system transition planning in the first five years between GMCA, local authorities, Cadent and ENWL, reflected in local area energy plans across all 10 GM districts, is a precondition for success.

As the net-zero ambition can only be achieved through balanced progress across all the areas of demand and supply, it is important to track progress and mitigate possible risks. Keeping track of progress is therefore essential to ensure key milestones are achieved on time, and focus is maintained. A comprehensive set of indicators should be selected for monitoring and made publicly available online to ensure broad engagement and accountability of key stakeholders.

The transition to predominantly using hydrogen for space heating requires an equal amount of detailed planning on the grid side too. Supply of hydrogen to the region needs to grow in step with demand, and as GM starts moving from a blended to a pure hydrogen network detailed planning of the cut-over on a street by street basis is required. To ensure security of supply, hydrogen storage requirements arising from seasonal demand fluctuations and, as more green hydrogen starts to be produced, weather-induced intermittency, need to be understood and planned for.

For kickstarting this part of the transition, we therefore recommend the following priority actions for the 2021-2025 period.

2021-2025	Key Actions	ID
	• GMCA should lead the formation of a shared planning, monitoring and resource hub with Cadent and ENWL that provides data-driven insight into network capacity, spatial planning, tracks progress and can act as an advisory body for participants in the building, industry and transport sector on the nature and timing of interventions.	K7
	• GMCA should conduct a detailed building stock survey to prepare for large-scale renovation of the building stock. The results should be made publicly available. It is recommended to use existing data sources and platforms such as the EPC Rating database and Open Street Map for this. The building stock survey serves as a key resource for planning and tracking building interventions and monitoring their impact.	K8
	• Cadent, HyNet and National Grid should engage in detailed local gas network planning on the rollout of H_2 to GM and the geological storage requirements that result from the transition to hydrogen. In parallel, Cadent, National Grid, HyNet and others should undertake detailed regional gas network planning to create a North of England Hydrogen Zone which will increase access to various sources of hydrogen, improve security of supply, broaden access to hydrogen storage.	K9

GM features a number of important local and national transport hubs that are important to its economy. Heavy road freight using these hubs, either as transit or destination traffic, produce emissions that need to be curbed for carbon or air quality purposes, or both.

In GM, we expect biofuels to provide up to 20% of the energy for Heavy Goods Vehicles by 2038 but at the national level this is expected to be up to 33% by 2050, making it a very significant element of the future decarbonised energy system. For this to materialise, biofuels need to be available in GM to meet demand arising from road transport exogenous to the region.

2026-2030	Key Action	ID
	GMCA should coordinate with the Dept. of Transport, Cadent, National Grid, BEIS and others on the planning for the long-term supply of bio-methane (large scale AD and or Bio-SNG) for heavy road freight at key transport hubs (M6, M60, M61, M67 etc)	K10

From the mid-2030s onwards, Hydrogen Clusters are expected to grow into Combined Zones that expand geographically well beyond the initial end-users, as described in our *Pathways to Net Zero*[18] report for ENA that underpins this work. This increases the benefits for converting parts of the NTS to hydrogen, which in turn stimulates the connection and combined operation of assets across zones. Emerging hydrogen markets replace initial point to point commercial arrangements.

As a front runner, GM is likely to be affected by the changing dynamics that result from its inclusion in a large North of England hydrogen zone.

[18] Section 3.5.2: Creating Larger Hydrogen Zones, in the Pathways to Net Zero

3.2 Transforming the demand base

Transforming the demand base
Decarbonise across all sectors by switching to hydrogen, green electricity and biofuels.

- Improve energy efficiency of the building stock and deploy low carbon heating systems
- Deploy smart solutions and storage for demand side management
- Switch transport and industry to low-carbon fuels

In energy systems, demand and supply need to be balanced and GM's energy system is no exception to this. This holds not only for GM as a whole, but also for individual energy carriers like electricity and hydrogen. Storage and conversion techniques can help overcome mismatches in time and at the individual commodity level. During the transition to a fully decarbonised energy system, the relative importance and absolute quantities of some energy carriers change dramatically, making the challenge of matching supply and demand more prominent than in a relatively ready-state system. Hydrogen is probably the best example of this. It is predicted to play an important role in the decarbonisation of buildings and industry, and to a lesser extent for transport. All these sectors will experience strong electrification, with the electrification trend being most prominent in the transport.

Based on existing plans for HyNet and the stakeholder consultation conducted as part of this work we conclude that the supply of hydrogen to GM is not likely to be a limiting factor and will be able to keep up with demand from GM. We therefore propose a demand-led transformation pathway and will detail the transformation of demand first.

Each of the demand sectors (Buildings, Transport, Industry) is characterised by markedly different challenges when it comes to decarbonisation that will require a different approach to interventions and a different role for GMCA. The transition to electric personal vehicles is very much characterised by individual decisions, enabled by relatively modest capital requirements and payback times that fit with the financial planning perspectives of consumers, whereas building upgrades are typically best done lot by lot, requiring more coordination, more capital and present payback times that transcend the financial planning horizon of most home owners. In industry, any decarbonisation effort should not only pay for itself but more than anything not introduce any risk to the primary production process.

Because of these differences, the primary lens of our pathway is a sectoral one, rather than an energy carrier one.

3.2.1 Buildings

The building stock of GM accounts for over half of the energy demand by 2038 and full decarbonisation is therefore crucial to meet the net-zero target. Upgrading buildings means both improving energy efficiency of the building stock and deploying low carbon heating systems. Investing heavily in energy efficiency is key: what you don't consume, you don't need to decarbonise. Additionally, increased insulation levels open up possibilities for cost-effectively deploying hybrid heat systems and, to some extent, all-electric solutions

Energy efficiency measures are also beneficial when it comes to generating popular support: residents enjoy higher comfort levels from Day One when interventions like double (triple) glazing and roof and floor insulation are put in and see the impact on their energy bills shortly thereafter. Longer-term health effects can also be observed from living in better quality buildings.

However, the transformation of the building stock is complicated, costly and labour intensive, due to the wide variety in buildings, ownership structures, affluence/willingness to pay for upgrades, breadth of solutions and the need to respect customer choice. In the first part of our pathway, *Kickstarting the transition*, a lot of emphasis is put on developing a deep understanding of the technical and social-economic factors impacting retrofitting options, in building the required workforce and innovating the required solutions which together will inform the timing and the nature of the retrofit.

It should be made clear that for GM to reach its target per the balanced scenario presented here, GM needs to renovate its building stock at a rate not seen anywhere else, ever[19]. One important consequence of this is that there is only time to upgrade every building once[20] and it is therefore important to coordinate planning of interventions and e.g. install solar PV together with roof insulation to reduce the required labour, costs and inconvenience.

Many (innovative) building upgrade solutions have been tried at a limited scale but for GM to meet its targets they need to be deployed at a rate hereto unseen. In the first five years, the focus should be on trialling deployment of interventions at scale (>1000 buildings per project) and package proven solutions into easy-to-deploy services that include incentives and financing solutions. This will be a mechanism to design and deliver GM Retrofit Accelerator[4] capable of supporting 60K+ low carbon home upgrades (retrofit) per year.

Intermittent renewable energy sources, increased electrification and the need to use network assets to maximum effect create a need for flexibility in supply and demand. Upgraded buildings can provide this, especially when solutions for heat and electricity buffering are deployed. As part of developing and trialling solutions at scale, Building Energy Management Systems (BEMS) should be piloted. These systems control on-premises energy assets to achieve (user-defined) goals that can range from maximising the use of self-generated energy to maximising profit on local energy markets while maintaining pre-set comfort levels. As such they are a key ingredient for local grid management and portfolio optimisation. Buildings-to-Grid (B2G) capability will ultimately provide local flexibility with an ability to use buildings as both a source and a sink of energy depending on need and economics, however how best to manage this and ensure that operation and system design respects those using the building as well as those owning and managing the building will benefit from further work.

The development of zero carbon standards and pathways for new buildings that GMCA has announced for the next 12 months can act as a stepping stone for improving building quality and energy performance but will need to be augmented by an approach that is both stricter and more collaborative. To provide clarity on objectives, stimulate innovation and create a level playing field, GMCA should develop mandatory building codes, regulations and incentives for new and existing buildings with a view to the net zero target. Options for local regulation and covenants with building developers should be used to achieve this if national building codes are insufficient.

At the same time as the energy efficiency of the existing building stock is improved, heating systems need to be adapted to provide low-carbon heat in the future. Where energy efficiency can be upgraded to at least a C standard, hybrid heating systems will prove to be the most cost-efficient solution. When a hybrid heating system is installed in a building, any existing gas boiler could be retained, with an electric heat pump plumbed into the system and a new control system added. It may, however, be beneficial to replace the boiler at the same time to a “hydrogen ready” version, although these are not expected to be commercially available until 2026. The advantage of hybrid heat systems is the fact that they reuse existing gas infrastructure, smaller and lower cost heat pumps are needed, and the required energy efficiency gains are lower (compared to all electric heat pumps) thereby minimising customer disruption and costs. They enable a robust pathway since building renovation, installing the heat pump, and decarbonising electricity and gas can take place independently. Once installed, they provide system operators with increased resiliency by allowing shifting demand from electricity to gas and vice versa, and enable fuel arbitration by end-users based on price incentives and market conditions.

In addition to policy instruments that enforce energy efficiency gains such as mandatory building codes, GMCA should develop incentives that provide demonstrable financial gains to early adaptors. Examples of this would be linking council tax to EPC ratings, work with financial institutions to provide soft loans for building renovations and reduced environmental inspection rates for business that meet certain energy efficiency standards.

[19] See also Section 2.3.

[20] Save for minor upgrades like replacing the burner unit on a previously installed hydrogen boiler when a street’s gas grid gets converted to hydrogen.

The installation of new heating systems will need to start as soon as possible and ramp up quickly: the number of required hybrid heat systems and all electric heat pumps grows from 92,500 and 19,500 in 2025 to 666,500 hybrid heat pumps and 57,700 all electric heat pumps by 2038 (see figure 19).

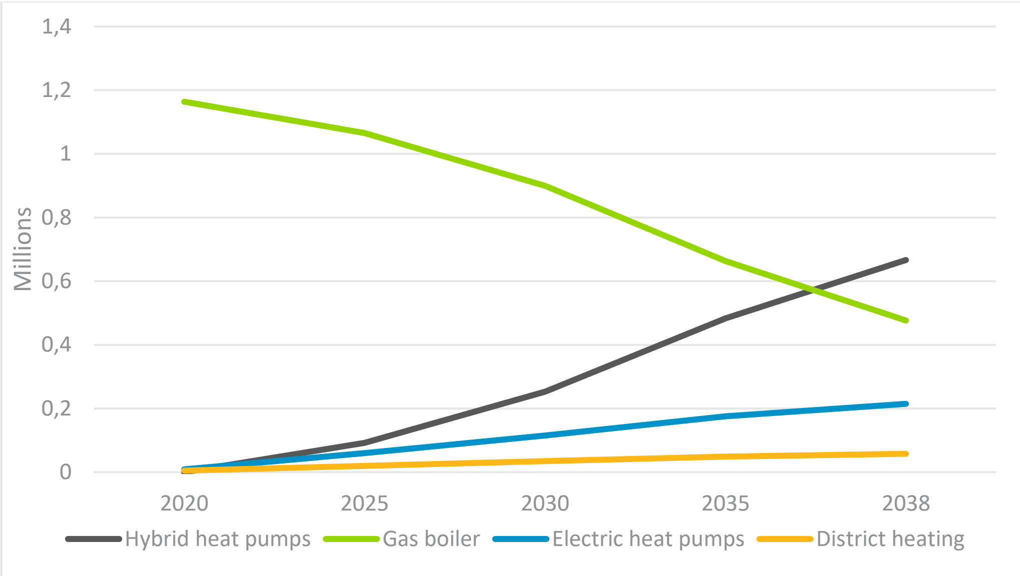


Figure 19: Evolution of heating technology in GM

2021-2025	Key Actions	ID
	• GMCA should design and enforce mandatory building codes, regulation and incentives for new and existing buildings with a view to net zero	D1
	• GMCA should create an incentive scheme to promote uptake of hydrogen-ready boilers and cookers by homeowners	D2
	GMCA should work with the building sector to execute large-scale demonstration projects (1000+ homes) for building upgrades which include building insulation, low carbon heating systems and supporting hydrogen-ready devices (boilers, cookers etc.)	D3
	Cadent, ENWL, energy retailers and energy service companies should pilot BEMS for in-building optimisation of energy usage	D4

In the second five-year period of our pathway, the upgrading of the building stock should start at scale and quickly reach the levels required to upgrade the full stock by 2038, tentatively estimated at 300-400 buildings per day. Recognising that even in this phase there are likely still lessons to be learnt and that technological and financing solutions need to be refined and tailored to specific sections of the building stock, it is recommended to start with buildings that are more easily accessible and where financing options are less challenging, such as building stock owned by housing corporations and large investors. It is recommended to facilitate early movers among private homeowners through generous incentive schemes for low-carbon heating solutions, including hybrid heating systems, as they can act as lighthouses and ambassadors for the more challenging parts of the building sector that need to be tackled in the next stage of the pathway. Financial innovations and 'as-a-service' solutions matured through the proposed innovation and scale-up agency as well as incentive schemes co-developed and operated by GMCA would enable the financing of this.

Previously developed building codes and regulation should start bearing fruit, resulting in all new buildings being sufficiently energy efficient to be heated with all-electric heat pumps.

With more buildings being moved to all-electric heating (predominantly new construction), local energy markets being deployed at scale and the electrification of private transport in full swing, ENWL, with the support of Cadent, energy suppliers, commercial aggregators, energy service companies (ESCOs) and other stakeholders like fleet operators, should start deploying Building-to-Grid (B2G) and Vehicle-to-Grid (V2G) solutions for grid management and renewables integration.

Period	Key Actions	ID
2026-2030	GMCA should enforce the requirement for new homes/buildings to be built to a standard that enables the use of all-electric heat pumps	D5
	GMCA should work with housing corporations and large investors owning commercial and residential properties to start the large-scale upgrading of the existing building stock, achieving a rate of 400 properties per day by 2030.	D6
	Cadent, ENWL, energy retailers and energy service companies should start the deployment of B2G and V2G and other demand side management technologies (smart heating controls and IoT white goods etc.) for renewables integration and grid management	D7

In the early 2030s the large-scale upgrading of the building stock will need to be expanded to the more challenging and difficult to reach parts of the building sector while sustaining the same renovation rate. This specifically includes privately owned homes. Only a very limited part of those are detached, which means most of the homeowners share a roof and/or walls with neighbours. From a technical, effort, and financial perspective retrofitting preferably is done for an entire apartment building or terrace at once, but different life priorities, and affluence levels can make alignment between homeowners challenging. Low-risk, low-investment options with clear pay-back times are essential here for making the aggressive upgrading schedule.

By this time, hydrogen from HyNet will be delivered to the GM area enabling the area by area conversion of the gas grid (until then operating on a hydrogen blending regime) to a hydrogen-only grid. See also Section 3.3.2. This requires previously installed hydrogen-ready boilers and cookers to undergo a relatively simple upgrade to use 100% hydrogen burners.

Flexibility will continue to be a key option for managing the power grid. More and more Internet of Things (IoT)-enabled devices will find their way to buildings and can be intelligently controlled and pooled to take part in demand side management programs. The Local Energy Markets that GMCA helped being developed and trialled in the first five-year period (S2), and that now can be deployed at scale (S6) provide the infrastructure for generating revenue from the flexibility such devices unlock.

Period	Key Actions	ID
2031-2035	GMCA should work with installers, contractors and homeowner associations to expand the large-scale upgrading to include more challenging and difficult to reach parts of the building sector while maintaining a renovation rate of 400 properties per day.	D8
	• Energy suppliers, appliance manufacturers and energy service companies should start converting hydrogen-ready devices to run fully on hydrogen	D9

	where needed and applicable, as the natural gas grid gets converted street by street to a hydrogen grid. • Cadent, ENWL, energy retailers and energy service companies should expand the use of demand side management technologies (smart heating controls and IoT white goods etc) to unlock more sources of flexibility in the residential and commercial domain	D10

In the final stages of the pathway for the building sector, upgrading of the building stock is completed, including the deployment of hydrogen boilers and cookers, and conversion of previously deployed hydrogen-ready devices, as the area-by-area conversion of the gas grid to run on 100% hydrogen is completed.

	Key Actions	ID
2036-2040	GMCA should work with the building and energy sector to complete the upgrading of the building stock and the roll-out of hydrogen-ready devices	D11
	Cadent, ENWL, energy retailers and energy service companies should continue to switch hydrogen-ready devices over to 100% hydrogen as the grid conversion continues	D12

3.2.2 Transport

Greater Manchester's population and economy are expected to grow considerably in the future, which will put a strain on the city-region's transport system and increase its environmental impact. Road transport already poses some of the most urgent and acute threats to the urban environment and its residents. Pollution from vehicle tailpipes causes roughly 1,000 deaths annually and is responsible for a third of the area's carbon emissions. GM is planning the introduction of a Clean Air Zone which would address the immediate issues by limiting the presence of the most polluting commercial vehicles from 2021.

Following the devolution of powers and funding, GM has taken a long-term view on the transport system and has formulated the *Transport 2040*[21] strategy, which has environmental protection and improved quality of life among its key elements. The document sets a clear target for zero-emission road transport by 2035. To achieve this target, GM needs to develop a range of low carbon alternatives to passenger car travel and invest in alternative fuels like electricity.

Sustainable modes of transport

As with energy efficiency in the building sector, reducing reliance on road transport is key to tackling emissions from transport. In line with the idea that "what you don't consume, you don't need to decarbonise," the role of sustainable transport modes like walking and cycling needs to grow. GM aims to increase the share of sustainable transport modes from 49% in 2018 to 60% by 2040. To achieve this, GMCA should ensure the implementation of the ambitious *Bee Network* – a plan for an 1800-mile cycling and walking network that will connect the whole city-region and prioritize the construction of the busiest routes in commercial areas and around universities and schools.

Public transport

For commuters unable to walk or cycle, a widely accessible and efficient public transport system is the main alternative to car travel. GM needs a well-integrated bus system and to continue developing the Metrolink tram network and Bus Rapid Transit links. Metrolink is being expanded to Trafford Park

[21] Greater Manchester Transport Strategy 2040. Available at: https://tfgm.com/2040

and planning for further expansions should continue because it is currently the most effective way to reduce energy consumption and therein carbon emissions in medium-distance commutes.

Reducing emissions of the bus fleet is a gradual process, which the GMCA needs to drive together with local bus operators. There are many potential low- and zero-carbon solutions emerging for bus operators, however, the trajectory among transit agencies globally is towards battery electric buses (BEBs). GM needs to plan for BEB adoption and identify strategies to make the legacy fleet cleaner through either engine retrofits or increased biofuel use.

Public transit agencies worldwide are turning towards BEBs because they are often determined to be the most cost-effective way to attain a zero-emissions fleet. BEBs have attractive cost savings for energy and maintenance and vehicle acquisitions costs have been falling because of dramatic battery cost declines over the last decade. Even so, private bus operators may be reluctant to invest because BEBs are still more costly than conventional buses, and infrastructure deployment costs are high. It is unlikely that operating cost savings will yet pay back capital expenses without subsidies. Funding from the government’s Ultra-Low Emissions Bus Scheme is available to cover up to 75% of the price difference between diesel buses and BEBs. If GMCA decides to introduce a bus franchise, then requirements on the rate of BEB adoption may become part of the franchise framework.

Given there are multiple bus operators, it may be cost-effective to develop a shared charging infrastructure system in coordination with ENWL. In pursuing a shared solution, it will be important to identify an interoperable charging standard for the region. The GMCA should lead by identifying optimal charging locations that among other things, consider spatial constraints, grid capacity, and grid connection costs.

Other low- or zero-carbon options for buses include biogas and hydrogen. Under certain conditions, biogas consumed in a CNG-powered engine may be a reasonable solution for a bus fleet. However, if this is considered, it is critical to thoroughly evaluate life-cycle emissions and production capacity of available biogas feedstocks relative to available electricity generating resources. Hydrogen consumed in fuel cell powertrains is in an early phase of commercial development. The vehicle, infrastructure, fuel, and maintenance costs are all much greater than those of a BEB solution. This may change as development of fuel cells globally progresses and economies of scale produce cost declines for hydrogen production systems, storage, and fuel cells. In fact, a number of cities in the UK are already trialling hydrogen buses, including Liverpool which received £6.4 million of government support to put 25 hydrogen buses on its streets. If successful, these pilots may accelerate the commercialisation of hydrogen buses, potentially making them a preferred alternative to BEBs - this is a technology to monitor.

For long-distance commuters, good regional rail links are key. To ensure maximum use of regional rail transport, rail congestion around GM needs to be resolved and infrastructure upgraded. Given the net zero emissions target, it is crucial that all regional rail lines are electrified and projects like the Trans Pennine Upgrade (part of the broader High Speed North initiative) are delivered as soon as possible. Where the economic case for whole rail line electrification is weak (e.g. on less busy lines), the switch to hydrogen trains could be considered in the future as costs of hydrogen-powered trains decline and considerations are made for refuelling infrastructure.

EV infrastructure

Passenger cars are currently the largest energy user (and carbon emitter) among road transport modes in GM. Outside of shifting passenger car use to more sustainable transport modes, electrifying the passenger car fleet is the most important lever to decrease transport environmental impacts. EV purchase subsidies are a critical adoption driver, but so is the availability of charging infrastructure outside the home. Chargers deployed for public use and for workplaces help overcome driver range anxieties and open EV ownership potential to drivers who are unable to install a charger at their residence. To meet GM’s 2035 target, it is essential that a broad network of public EV chargers be rolled out throughout the city-region. The priority should be placed on strategic locations with the largest number of visiting cars, e.g. near high streets, government buildings, schools and universities. Planning should be coordinated between the GMCA, districts and ENWL and consider spatial constraints, grid capacity and connection costs, and plans for the development of urban spaces.

Given the size of GM's registered passenger car and light commercial vehicle (LCV) fleet, an estimated 100,000 Level 2 public EV chargers would be required to accommodate 100% fleet electrification. To ensure that the required number of EV chargers is installed in time, local authorities will need to develop an infrastructure roll-out scheme that incentivizes EV charging operators to invest at the required locations, whilst the distribution grid is adequately reinforced. Such a scheme could include loans or partial subsidies for the initial wave of EV chargers needed to kickstart the electrification process. Owners of commercial properties like shopping centres and office buildings should be encouraged to install public EV chargers for users visiting their premises.

Heavy Goods Vehicles

The decarbonisation of heavy goods vehicles (HGVs) is expected to go down three routes: electrification, hydrogen used for fuel cell powertrains, and biomethane (in the form of Bio-CNG or Bio-LNG depending on vehicle duty cycle and routes). HGV applications that have predictable daily routes and return to dedicated parking and maintenance facilities are likely to be electrified. This typically consists of vehicles weighing between 3.5 and 16 tonnes serving urban customers. Heavier vehicle classes that typically serve long-haul functions, specifically semi-trucks, are more difficult to electrify and hydrogen and biomethane are reasonable alternatives.

The challenge for semi-trucks is the refuelling infrastructure solution and the availability of long duty cycle OEM products. EV charging is the least developed, however, the two main standards bodies for the global EV charging industry are currently developing standards for solutions that would deliver near to or over 1MW. Solutions for hydrogen exist today but stations are rare, and development is expensive. Costs for hydrogen are also high. Biomethane through CNG or LNG is currently the most feasible deployment option, but the decarbonization potential depends significantly on the availability of low- or zero-carbon biomethane feedstocks, which may be limited.

To enable the decarbonisation of HGVs, GMCA should plan for electrified urban fleets and monitor alternative fuel vehicle developments for semi-trucks. As a significant portion of HGVs will be electrified (the urban fleet), GMCA should work with ENWL and with fleet operators to determine likely challenges and solutions for preparing the distribution grid. These two groups need to work together and better understand each other's business models and limitations to more accurately determine expectations for fleet electrification.

For semi-trucks it is important for the GMCA to coordinate with industry associations and national initiatives on infrastructure development. GMCA should assess existing refuelling infrastructure patterns for semi-trucks in the area and gauge the ability of private developers to support automaker and fleet deployments of electricity, hydrogen, and/or biomethane-powered vehicles with respective refuelling infrastructure solutions. GMCA should also look to support fleet operator led pilots and tests of the alternative fuel vehicles.

	Key Actions	ID
2021-2025	• GMCA and districts should implement the *Bee Network* - a walking and cycling network covering all Greater Manchester	D13
	• GMCA should make use of available funding to create additional incentives for bus operators to start adopting battery-electric buses (and compare these to hydrogen-based alternatives)	D14
	• GMCA needs to coordinate the selection of bus charging standards, identify locations for bus depots and coordinate with ENWL and bus operators the development of shared electric bus depots	D15
	• GMCA needs to work with ENWL to plan for a target network of an estimated 100,000 public EV chargers throughout Greater Manchester.	D16

	Implement incentives for charging network operators to install 19,000 public EV chargers by 2025	
	• GMCA should work with the transport sector organisations to assess demand for charging/refuelling stations for heavy goods vehicles and identify key locations for station operators to invest in	D17

In the 2026-2030 period, the public EV charging network should be expanded beyond priority locations to lower priority areas like residential neighbourhoods. All government and commercial buildings should have an appropriate number of EV chargers available to charge within 1-2 hours when visiting their premises.

Fleet operators serving urban environments should have clear guidelines and approaches for expanding charging infrastructure capacity at fleet depots. The distribution network operator should in-turn have a robust program and solutions in place to process and develop requests for grid connections.

There are likely multiple alternative fuel solutions being tested and piloted for semi-trucks in this period. These solutions will be in competition with each other and it will be important for the local authorities to support all solutions, but to do so to the extent of the solution's feasible emissions reduction potential and benefits for local air quality.

In the 2026-30 period, Metrolink needs to be expanded to less accessible parts of Manchester and tie into existing public transport networks through multi-modal transport hubs. Whilst current electrification projects, e.g. on Trans Pennine and Bolton rail links, are being completed, the GMCA should continue working with Network Rail to identify the best way to decarbonise remaining non-electrified rail lines. Hydrogen trains will be past their demonstration phase and could be considered as a viable option for decarbonising rail transport.

2026-2030	Key Actions	ID
	GMCA should continue the stimulation of a shift to sustainable modes of public transport for both medium- (Bus Rapid Transit and Metrolink) and long-distance commuters (regional rail)	D18
	• GMCA and ENWL should work with charging operators to expand the EV charging network beyond top-priority locations including residential areas to reach a network of 52,000 public EV chargers by 2030.	D19
	• GMCA should work with bus operators to ensure that over half of the bus fleet is decarbonised to hydrogen or electricity by 2030.	D20

To meet GMCA's target by 2035, the whole light road transport fleet will need to be decarbonised. This requires full coverage of a public EV charging network – e.g. all vehicle users need to have a feasible charging solution; home, public, workplace or other. Of note, there is a discrepancy between local and national-level targets: GM aims for a zero-emissions car fleet by 2035, but the national target is that by 2035 all new vehicles sold will be fully electric or zero-emissions. GM must consider how this discrepancy may impinge on its ability to meet its targets and plan ways to mitigate impacts. Two possible considerations are scrappage schemes that accelerate ICE replacement with zero-emissions-vehicles and the extension of GM's clean air zone to all forms of non-zero-emission (light) road transport.

Costs for batteries are declining rapidly[22], increasing the probability that EVs in light classes, for buses, and for urban operating HGVs will be highly cost competitive (on a total cost ownership basis)

[22] For a projection of future battery costs please see: https://www.ucsusa.org/resources/ev-batteries

with ICE-equivalents by 2030. It is likely that in some of these segments the market is well on its way to completing a full transition. The semi-truck class at this point is likely tracking towards a specific alternative: electricity, hydrogen, or biomethane. It is critical across all vehicle classes that GMCA is monitoring developments and ensuring they progress in line with emissions reduction targets both at the tailpipe and in the upstream fuel supply chain.

2031-2035	Key Actions	ID
	GMCA should introduce a scrappage scheme for ICE vehicles and zero-emissions zone covering all forms of (light) road transport to meet the 2035 zero emission target	D21
	• GMCA and ENWL should work with charging operators to complete the development of a public EV charging network and reach 100,000 public EV chargers by 2035.	D22
	• GMCA should work with bus operators to ensure that the whole bus fleet is decarbonised by 2035.	D23

To meet the 2038 net zero target, HGVs will also need to be fully decarbonised. This may prove difficult to achieve given the discrepancy between the national and local level of ambition. To accelerate the transition of the local HGV fleet, the currently planned zero-emissions zone needs to be reinforced to appropriately penalize any polluting HGVs, e.g. with a high charge put in place for vehicles that do not meet the zero-emission standard.

2036-2040	Key Actions	ID
	GMCA should ensure the zero-emission zone effectively deters non-zero-emission heavy-duty vehicles from 2038 on, in order to reach its net zero carbon target	D24

3.2.3 Industry

Greater Manchester has a significant industrial sector, dominated by industries such as food, textile, fast-moving consumer goods (FMCG), paper and glass production. The decarbonisation of industry is a complex process due to the variety of industrial sectors and their specific characteristics, however it is vital to making progress on the decarbonisation pathway. Given the length of investment cycles, industrial players need to start planning for a net zero-carbon future today. Sector leaders face difficult decisions related to manufacturing process change, technology and fuel choice. Industrial assessments can identify appropriate technological options, but the economics will depend on timing, fuel availability and costs. The GMCA should engage with the private sector through enterprise boards to provide clarity on GM's environmental strategy and regional planning, including future availability of energy and transport infrastructure, as well as the expected supply of electricity, hydrogen and biofuels.

Industrial feasibility studies will need to be made separately for each sector to identify the most optimal decarbonisation solution for industry in GM. Ideally, such studies should be carried out for industrial clusters, in order to take advantage of synergies (e.g. reusing waste materials) and maximizing economies of scale in the use of infrastructure, such as pipelines for hydrogen or additional electrification investment. Rethinking manufacturing methods may provide an opportunity for new process design with additional benefits:

- improved energy efficiency: for instance, gas CHP or commercial boilers can in some industries be replaced with commercial grade heat pumps which consume significantly less energy;

- elimination of heat production, e.g. in certain industries drying can be done with the use of microwaves;
- maximizing material recycling to reduce the need for fuel procurement. For instance, paper production leads to a lot of biowaste which can be reused as biomass for heat production.

There are significant costs associated with decarbonising industrial processes both in terms of capital expenditure and operational costs. In the initial phase, industry will rely on government incentives to switch to clean technologies – government grants for industrial innovation (like the UKRI's Industrial Decarbonisation Fund), preferential loans and carbon contracts-for-difference can support investment in clean technology. Operational costs will depend on the relative price of electricity, natural gas and hydrogen in the future and will determine which fuels are preferred by industry. Industrial exemptions from certain taxes and levies may make certain fuels more favourable (as is the case with renewable electricity).

The sequencing of industrial decarbonisation will depend on the availability of low-carbon industrial equipment, as well as the relative cost of industrial decarbonisation. Some countries, like the Netherlands and Germany, have started running competitive auctions to allocate government support. Such schemes prioritize the lowest-cost decarbonisation projects and, as such, impact the timing of the transition.

From a technical point of view, a number of industrial processes can already be electrified, e.g. gas boilers for steam production in food, paper and textiles production can often be replaced with electric boilers or electric heat pumps, depending on the grade of heat required. The relative attractiveness of each of these will depend on the nature of the industrial process, including the required heat temperature or running profile of the boiler. Industries which decide to switch to hydrogen can over time start purchasing equipment that is hydrogen-ready to gradually prepare their operation for the switch to hydrogen.

2021-2025	Key Actions	ID
	• GMCA should develop incentive schemes to encourage energy efficiency and fuel recycling in industrial processes	D25
	• Cadent and ENWL should work with industrial clusters to assess and select the most optimal decarbonisation options to maximize synergies and economies of scale in the use of energy	D26
	• ENWL should work with industrial facility owners and operators to start electrification of industry where technically feasible and lowest cost	D27

During the 2026-2030 period, certain new technologies are expected to become available, enabling the transition of further industrial sectors. For instance, hydrogen boilers can be used to replace gas boilers or CHP used for low temperature (<140°C) heat production in multiple industries such as food or paper production.

The HyNet network is expected to reach GM within this timeframe. Trafford Park will be the first area to be supplied with blue hydrogen providing manufacturers in that area the option to switch from natural gas to hydrogen and become carbon neutral. The switch to hydrogen will have to be carefully planned and managed: industrials will need to be make sure all their equipment is hydrogen-ready, new processes and safety procedures will need to be in place and staff appropriately trained.

As the price of carbon increases, driven by policy measures, the relative cost of electricity and blue hydrogen will decline compared to natural gas. This will make the economics of industrial decarbonisation increasingly more favourable.

2026-2030	Key Actions	ID
	• Cadent should plan and manage the supply of hydrogen from HyNet through a new dedicated network to supply industry	D28
	• Industrial equipment manufacturers and facility operators should prepare equipment (e.g. boilers) and industrial processes to be hydrogen-ready	D29
	• Industrial facility owners and operators should continue electrifying low-temperature processes as electrification costs decline	D30

During this period further new technologies will become available to replace conventional equipment that runs on natural gas. An example are float baths in glass production which will be able to operate on electricity or hydrogen, reducing carbon emissions from this carbon-intensive industry.

The HyNet consortium expects that blue hydrogen from HyNet will become cheaper than natural gas (including the cost of carbon) by 2035. This will be an important tipping point which will make the switch from natural gas to hydrogen commercially viable without government or local authority incentives. An acceleration of the decarbonisation of high-temperature processes can be expected around this time.

2031-2035	Key Actions	ID
	• Cadent should support the acceleration of hydrogen-switching in industry, coordinating and planning for effective mass adoption	D31
	• Industrial equipment manufacturers and facility operators should continue the replacement of equipment and decarbonisation of processes	D32

To meet GM's 2038 net zero target, all industrial processes should have been decarbonised by this date. However, some industrial emissions are unavoidable as they are a product of chemical processes, e.g. in glass production. In such cases, the carbon will need to be captured and managed, either through utilization in other processes (e.g. production of synthetic gases) or sequestered. CO_2 from GM could be transported via a pipeline to Liverpool Bay which has abundant CO_2 storage capacity. However, the cost of carbon capture, utilization and storage (CCUS) would be prohibitive for a single glass manufacturing plant. Instead, production facilities requiring CCUS would need to be grouped into clusters to drive costs down by sharing CO_2 transport and storage infrastructure.

2036-2040	Key Actions	ID
	Cadent and industry should collaborate to capture remaining emissions produced within industrial clusters and utilize the carbon or transport for CO_2 storage.	D33

3.3 Securing low-carbon supply

The third main track of our pathway focuses on securing low-carbon supply for electricity and hydrogen. For electricity, the main actions deal with increasing local clean generation, embedding flexibility options to support renewables integration and offsetting remaining emission from National Grid imports. A consequence of increasing electrification of Greater Manchester's energy system is a need for selective grid reinforcement which is also discussed in our pathway.

In our balanced scenario, hydrogen from HyNet will be the dominant energy form for space heating and high-temperature process heat. In this part of the pathway we indicate which key actions are required to convert GM's gas grid to be hydrogen ready and supply it with increasing levels of hydrogen, as production from HyNet ramps up and its supply of blue hydrogen is complemented by green hydrogen from renewable electricity.

Securing low-carbon supply
Meet low-carbon demand through more local generation and distribution of imported clean energy.

- Enable green and local electricity generation
- Reinforce electricity network to meet increased demand
- Convert the gas grid to be hydrogen-ready
- Supply the gas grid with hydrogen

3.3.1 Electricity

Electricity currently accounts for 21.4% of the energy demand in GM. Electrification of transport, heat and industry will see demand increase to 18.7TWh in 2038, representing almost half of the projected demand. This significant increase in demand is met in our pathway through the local generation of renewable electricity and importing increasingly green electricity from the National Grid. To distribute and integrate all this electricity, smart solutions and demand response are enabled through local energy markets network, augmented by network reinforcements where required.

Local generation overall is expected to increase by 425% in our scenario, with solar PV nine-fold to 0.9TWh by 2028, just under half of the total local generation. Rooftop solar PV provides an excellent opportunity for greening the electricity supply. Upfront investments are limited for residents and can be mitigated through tax incentives and “rent-a-roof” or “PV-as-a-Service” type propositions. Financial benefits stay largely within the community and the installation can be combined with other building upgrade activities to minimize the inconvenience for residents.

Local generation

GMCA currently has a target of 45MW for local solar PV capacity additions by 2024, of which 10.5MW is already planned. To achieve the 0.9TWh suggested by the scenario, this would have to increase to 682MW corresponding to 7500 residential (4kW) solar PV systems installed annually until 2038.GMCA should therefore aggressively pursue the expansion of its solar PV community renewables program, accelerating and expanding beyond announced initiative like the promotion of the use of derelict, underused land for solar PV and supporting of large PV projects via ERDF and Go Neutral.

Energy from waste

Electricity from waste is currently the largest source of renewable electricity, accounting for 0.2TWh per year, predominantly from landfill, sewage and anaerobic digestion gas. Bury, Oldham and Trafford are account for most of the renewable generation from these sources. In our Balanced Scenario, electricity from waste and biomass is expected to increase 0.8TWh and 0.1TWh annually, respectively, requiring a strong effort from GMCA to unlock the potential and stimulate the development of energy-from-waste plants.

Wind

The final form of locally generated renewable energy to consider for GM is wind energy. In our Balanced Scenario, it is expected to provide 0.1TWh per year which corresponds to roughly two-thirds of the technical potential[23]. Planning and permitting are challenging and time consuming as they often involve multiple landowners and interest groups involved resulting in lengthy public consultation and land expropriation procedures. In the *Kickstarting the transition* stage of our pathway, local policy options for stimulating onshore wind should therefore be explored. Districts with above-average potential for onshore wind are Wigan, Salford, Trafford, Oldham and Tameside[23].

Flexibility and Local Energy Markets

Local Energy Markets (LEMs) provide a great mechanism for integrating renewables, whose intermittency can be elegantly mitigated through demand response options. Additionally, LEMs can help manage grid congestion and maintain system balance as well as enhance a sense of community. LEMs are therefore expected to play a prominent role GM's future local energy system. In the first five years of this pathway track, trials should be undertaken that explore the viability, from an economic, social and technological perspective as to which trading and demand response options resonate best with GM's residents and how they can be best deployed to unlock the value of flexibility.

Grid capacity and LV monitoring

The planned substantial increase of both local generation and consumption will mean the electricity distribution grid will be operated closer to its nominal design capacity, and might, in certain locations, require grid reinforcements as the level of electrification of the building, transport and industry sectors increases. Current monitoring capabilities of the LV grid prevent detailed forecasting of the speed and impact of electrification and prevent assessing detailed effects to demand response events too. ENWL recognises this and will execute a £10m project to implement this across GM, which will be completed by the end of Fiscal Year 2023.

	Key Actions	ID
2021-2025	GMCA should streamline and shorten planning permission processes, identify key development areas and develop incentive schemes to: • Expand the local uptake of rooftop solar PV to reach 200MW installed capacity by 2025 • Onshore wind development in Greater Manchester • Develop energy-from-waste and biomass plants	S1
	• GMCA should stimulate collaboration between ENWL, energy retailers, energy service companies and aggregators to trial Local Energy Markets for peer-to-peer trading of electricity	S2
	• ENWL will expand the LV grid monitoring to assess impact of increasing loads from local generation, EV-uptake and electrification of heat by the end of Fiscal Year 2023.	S3

Small scale storage

The need for flexibility in the power grid will increase as more of GM's electricity is delivered through intermittent (locally generated) renewable energy. Behind-the-meter storage for both electricity and heat will enable further integration of renewable energy, and with costs expected to come down significantly (especially for home batteries) local storage is predicted to become an economically attractive option too in the second half of the decade. Next to battery storage for electricity, heat vessels for storing thermal energy can help with the extra consumption (electric heat pumps) or production (CHPs) of local electricity. It should be noted that space requirements for such solutions are not negligible and should be part of the integral planning of building upgrades.

[23] Greater Manchester Spatial Energy Plan Evidence Base Study – Full Report, Energy Technologies Institute, 2016

Grid connected storage

With more flexibility options being enabled in the grid and a clearer view on how to organise and operate LEMs they can be enabled at scale in GM. Looking ahead to near complete upgrading of the building sector, electrification of transport and industry and increasing local renewable supply, the need for flexibility should be contrasted to what can be provided by behind-the-meter solutions to inform the need for procuring grid connected storage options.

Grid reinforcement

Similarly, increasing levels of electrification and renewable supply, combined the effects of LEMs will inform priority locations for grid reinforcement.

	Key Actions	ID
2026-2030	• The GMCA should continue incentivizing rooftop solar PV to ensure that around 360MW is installed by 2030	S4
	• GMCA should work with the energy and building sector to collectively expand behind-the-meter storage for electricity and heat	S5
	• ENW, energy retailers, energy service companies and aggregators should enable Local Energy Markets and Demand Response at scale • ENWL should prioritise targeted electricity network reinforcement to support demand electrification	S6

Grid connected smart solutions

In the third five-year period of our pathway, a high degree of insight into the need for flexibility should exist, as well as a deep understanding of the potential of what can be provided through behind-the-meter smart solutions (BEMS controlling local assets including in-home storage, EV charging) and LEMs. The remaining need for flexibility should be met through grid-connected smart solutions, owned and operated by market parties. GMCA and ENWL, and to a lesser extent Cadent, should coordinate procurement of these options to meet demand.

Offsetting the impact of imported electricity

Despite a strong increase in local clean electricity generation GM will continue to have a need to import electricity from the National Grid. Although this too will see strong decarbonisation as indicated in Section 2.8 it is not expected to be fully decarbonised by 2038, creating a need for GM to offset the impact of National Grid imports. The expected level of decarbonisation can be gauged accurately in the early 2030s and this will inform what the most attractive options for offsetting are, see also Section 2.8.

Continued grid reinforcement

As electrification of the various sectors continues, selective grid reinforcements by ENWL will continue to be needed.

2030-2035	Key Actions	ID
	• GMCA should work with investors and residents to ensure that renewable electricity generation is nearing full potential by 2035, including 680MW rooftop solar	S7
	• GMCA should assess options for offsetting the impact of National Grid imports	S8
	• GMCA should coordinate with the energy sector for ongoing procurement of grid-connected smart solutions	S9
	• ENWL should continue electricity network reinforcement to support demand electrification	S10

Carrington CCGT

Carrington CCGT is a power station located in GM, which had new gas turbines with 884MW nameplate capacity installed in 2016. The turbines are not fully hydrogen-ready and can only handle up to 10% hydrogen in injected gas. It is unlikely that the plant owner would want to replace these turbines before they are amortized, i.e. before the end of their 25-year lifetime (i.e. around 2041). Since any power plant in the country will need to be zero-carbon by 2050, we expect the power plant to convert to hydrogen turbines around the year 2040, possibly after GM's local net zero target year.

The preferred options for managing the impact of electricity imports from the National Grid need to be implemented and electricity network reinforcement by ENWL will continue to meet increasing capacity needs.

2036-2040	Key Actions	ID
	GMCA should manage the impact of remaining carbon of electricity imports from National Grid	S11
	GMCA should work with Carrington CCGT to accelerate the conversion to low-carbon fuels before the end of the current turbines' full lifetime	S12
	ENWL should continue electricity network reinforcement to support demand electrification	S13

3.3.2 Hydrogen

Regional production of low-carbon hydrogen at scale will facilitate the timely and cost-efficient decarbonisation of the whole North West of England. In the 2038 balanced scenario for GM, an estimated 14TWh of zero-carbon hydrogen is required. Such quantities can be produced locally in the form of blue hydrogen (obtained from natural gas reformation and the use of CCS to manage CO_2 emissions) and green hydrogen (obtained through electrolysis of renewable electricity).

Blue hydrogen

A key source of blue hydrogen supply will be the HyNet project which brings together hydrogen production[24] at the Stanlow Refinery in Cheshire and other industrial end-users in the surrounding area. Carbon from industrial activities and blue hydrogen production will be captured and stored in the nearby Liverpool Bay. The HyNet project is currently in the Front-End Engineering Design (FEED) phase and should be "shovel-ready" by March 2021.

The project is being implemented in phases: the first phase will focus on providing CCS for industries located on-site, the second phase will ramp up hydrogen production and distribute it regionally (including to GM) through a dedicated hydrogen network. The start of hydrogen production is planned for 2025, in parallel with the development of 80km of distribution pipelines. In the third phase, the project developers hope to extend the hydrogen network throughout the North West region.

Blue hydrogen from the HyNet zone is expected to be cost-competitive thanks to the reuse of transport infrastructure and low-cost CO_2 and hydrogen storage assets in the region. Nevertheless, a supportive policy framework is needed for low-carbon hydrogen production to take off. The UK government is developing business models to support technologies such as CCS and blue hydrogen. It is likely that government will opt for a contract-for-difference scheme for hydrogen production given the good track record of an equivalent scheme for renewable electricity. It is important that regional authorities signal to central government the importance of policy support to ensure that an effective framework is adopted as soon as possible.

Green hydrogen

A zero-carbon alternative is green hydrogen produced through electrolysis using dedicated or otherwise curtailed renewable electricity. Green hydrogen is currently not cost competitive with blue hydrogen, although costs are expected to decline as electrolyser costs fall and the amount of low-cost renewable electricity increases. The advantage of green over blue hydrogen is that it does not require access to a gas feedstock or CO_2 storage. As such it can be located much closer to demand centres and may avoid some gas network reinforcements.

2021-2025	Key Actions	ID
	GMCA should work with the HyNet consortium and Cadent to ensure timely supply of hydrogen to Greater Manchester and communicate regularly on changing energy requirements	S14

The gas distribution companies are undertaking the iron mains replacement programme to install hydrogen compatible (plastic) pipework within their low-pressure networks. The programme will continue through the 2020s and is due to be completed by 2032.

The 2026-2030 period will mark the extension of the HyNet network to GM, initially for the purpose of providing hydrogen to industrial users in Trafford Park. Small-scale hydrogen storage tanks will need to be built close to the anchor users to provide the flexibility required to match the daily fluctuations of industrial demand.

A key challenge starting in this period will be to manage and coordinate the complex process of converting discrete sections of the gas network to 100% hydrogen. The conversion of the gas grid will follow a cluster-based approach starting with the sections of the gas grid heavily used by industry and, to a lesser extent, heavy goods transport.

[24] Through auto-thermal reforming with an expected 93% CO2 capture rate.

2026-2030	Key Actions	ID
	• GMCA should work with Cadent and industry to coordinate the switch of industrial users to hydrogen in a safe and timely manner, starting from Trafford Park	S15
	• GMCA should work with Cadent and industry to plan for appropriate hydrogen storage capacities required near the sites of anchor users	S16

During the 2031-2035 period, the conversion of the gas grid to 100% hydrogen will gradually expand into sections of the grid used predominantly by residential and commercial consumers. This will require a carefully planned area-by-area switching process which will start from the high-pressure segments and move towards low pressure parts of the grid. The switching will take place during the summer months from April to September when demand is low and alternative domestic cooking facilities can be provided, but no heating. The limited switching window and scale of the undertaking will require a large workforce of appropriately trained plumbers and gas fitters.

Hydrogen storage capacity will need to be built-up for long-term seasonal storage and to ensure security of supply, as the amount of hydrogen used for residential heating increases. The North West region has ample potential in salt caverns which can provide highly efficient and low-cost storage at scale.

The 2030s will see the growth of green hydrogen production as electrolysis becomes increasingly cost-competitive with blue hydrogen. Around GM, the key source of renewable electricity will be offshore wind located off the coast of the North West of England, as well as curtailed grid electricity in periods of excess renewable generation.

2031-2035	Key Actions	ID
	GMCA should ensure large-scale hydrogen storage is included in spatial planning activities	S17
	GMCA, individual districts and the DNOs need to coordinate the switch of residential parts of the gas grid, including a broad communication campaign aimed at residential and commercial consumers	S18

In the 2036-2040 period, the expansion of hydrogen clusters across the region will ultimately lead to the formation of a larger hydrogen zone spanning the North West, or possibly, the whole North of England. The NTS may play an important role in creating links across the hydrogen zone connecting multiple production sites, storage and end-users. This period will see accelerated growth of green hydrogen production and its integration into the hydrogen zone at scale.

2036-2040	Key Action	ID
	Cadent and gas suppliers should take advantage of increasingly cost-competitive green hydrogen opportunities by locating production closer to demand centres thereby avoiding the need for gas grid expansion or reinforcement	S19

4. PATHWAY CHALLENGES AND RISK MITIGATION

The pathway to deliver the 2038 Balanced Scenario for Greater Manchester (GM) sets out a “best view” timeline for the developments required until 2038, including the key actions to be undertaken by the main stakeholders. In practice, the pathway may be affected by several risks which may impact the implementation of certain key actions. It is important to recognise these challenges up-front and understand how they can be best mitigated.

4.1.1 Lack of or inadequate national policy for decarbonisation

Since the UK government announced its ambition to reach net-zero by 2050, there is a new urgency for key policies required to kickstart the transition, including in renewable heat adoption, renewable gas production, industrial decarbonisation, etc. The misalignment of national- and regional-level net-zero target timelines poses a material risk if crucial national policy and incentives are not introduced early enough for GM to meet its 2038 target. For instance, this is the case for industry and heavy-goods transport which are two demand sectors that require a comprehensive regulatory and financial support framework. Given the long investment cycles and the importance of long-term certainty, national decarbonisation policies affecting such sectors need to be in place as soon as possible.

This risk emphasises the importance of GMCA working closely with national stakeholders on the timely development and adoption of key decarbonisation policies. GM should highlight the accelerated target date it is pursuing and its implications for GM residents and local businesses. It is vital to understand the government’s planned policy timelines and identify where potential gaps may arise. Where necessary, the GMCA may need to step in to provide guidance or incentives for early actions that cannot be delayed until national legislation is adopted. For instance, investors looking to build a new manufacturing plant should be incentivised by local authorities to make “zero-carbon-ready” choices. The GMCA can work with local universities and research centres to advise such businesses on which low-carbon options are technically viable or what type of regulations may be introduced in the future.

4.1.2 Delayed or insufficient building stock upgrades

The scale of interventions required in GM’s building stock is immense. As indicated in the pathway, building upgrading needs to start at scale as soon as possible and will have to ramp up rapidly. The undertaking will require considerable mobilisation of financial, technical and human resources, concerted efforts from national and local authorities, as well as broad buy-in among GM’s residents and businesses. Lack of resources or insufficient mobilisation of any of the stakeholders will result in delays to GM’s decarbonisation plan.

It is important that the GMCA communicates clearly to residents and businesses the need for improved building upgrades and creates a positive image of investing in energy efficiency as a smart and socially responsible thing to do. Furthermore, a well-planned programme of building upgrades should identify high-risk areas of the building stock. The programme should develop from the building survey recommended in the pathway and consider factors such as the technical condition of the existing building stock, ownership structure, presence of fuel poverty, etc. A well-developed plan will enable the GMCA to prioritise high-risk sections of the building stock by targeting incentives where they are most needed.

4.1.3 Delays to the HyNet project

The HyNet project is well-advanced in terms of technical and economic planning, but the start of physical works is dependent on the introduction of government incentives on both the demand side (starting with investment in new industrial processes) and the supply side, specifically support for hydrogen production and carbon capture and storage. A regulatory framework will need to be in place soon for construction to start as planned in 2021 and for hydrogen to be delivered to GM around 2026, as currently envisioned. Apart from delays to the start of hydrogen production, the project developers also highlight risks to the timely construction of a dedicated hydrogen network, an undertaking requiring planning consent and coordination with various local authorities.

Given the above risks and long-time horizon, the date of first hydrogen delivery to GM is highly uncertain and needs to be accordingly planned for. Whilst certain activities, like the installation of hydrogen-ready appliances, can take place regardless of potential hydrogen supply delays, the conversion of the gas grid needs to be planned in modular and flexible manner. Workforce capacity planning and financing should consider potential delays and subsequent ramp ups of gas grid conversion process. If the supply of hydrogen supply is delayed or insufficient to meet total demand for gas, a larger role for biomethane in GM could be considered. Biomethane supply may be limited in 2038 so timely procurement and considerations related to biomethane transport to GM will be necessary.

4.1.4 Delayed or limited local renewable electricity generation

Local generation of renewable electricity will mainly depend on the adoption of rooftop solar PV, as well as investment in larger power plants producing electricity from waste and biomass. There are risks to the development of both types of installations. For instance, the former may be impeded by limited building owner uptake, whilst the latter may suffer from lack of investment or local opposition to such plants.

It is important that investors in both types of installations are incentivised to invest in new generation capacity. Following the removal of feed-in-tariffs for solar PV, property owners may need support with financing to make the payback period attractive enough. Subsidies or loans could be considered depending on the type of property owner. Local Energy Markets should be tested as soon as possible, as they have the potential to make returns on such investments more attractive. Waste and biomass plants compete for support in CfD auctions – the competitiveness of their bids can be improved through lower project capex. The GMCA should identify the lowest-cost brownfield land that already has a connection to the electricity grid and offer such sites to new power plant developers, whilst ensuring that the fuel (e.g. municipal waste) can be easily sourced locally.

APPENDIX A. STAKEHOLDER CONSULTATION

As part of this work a limited set of key stakeholders were consulted on their views on decarbonising Greater Manchester's energy system by 2038. Of particular interest to Cadent and ENWL were the views on how this work can best contribute to the existing body of work to create an actionable pathway Stakeholders were asked to reflect on the key challenges and opportunities in the regulatory, policy, technical, socio-economical and operational domains associated with GM's ambitious 2038 target. The consolidated views have informed the development of the pathway and the identification and prioritization of actions reflected therein. At a high-level, the stakeholders observed that:

- The success of GM's decarbonisation efforts has a strong dependency on national policy and clarity - which is lagging
- The transformation across building, transport, industry and energy sectors requires more centralized and detailed planning& execution
- To meet its target, GM needs to start with implementation now - There is enough insight from the collective body of research and strategy work to start. You don't have to know everything before you can start.
- Improved data sharing and transparency among stakeholders leveraging digital technologies would facilitate the transformation of high-level strategies into detailed plans
- There is a lack of knowledge on the potential role of hydrogen in the transformation of the building sector that needs to be addressed to prevent falling back to less optimal solutions

The stakeholder consultation was performed through semi-structured teleconference interviews, an unfortunate consequence of the COVID-19 pandemic that prevented in-person conversations. Next to internal expert groups at Cadent and ENWL, the following external stakeholders were consulted:

- Mark Atherton, Director of Environment, Greater Manchester Environment Team
- Sean Owen, Energy Lead / Regional Development Lead, Greater Manchester Combined Authority
- Roger Milburn, Greater Manchester Low Carbon Hub
- Amer Gaffer, Director, Manchester Fuel Cell Innovation Centre
- Ian Madley, Reader, Manchester Metropolitan University
- David Hodcroft, Strategic Planning and Infrastructure, Place Making Directorate
- John Egan, North West Regional Lead, Progressive Energy
- Peter Whitton, Managing Director, Progressive Energy

Cadent and ENWL would like to express their sincere thanks to them for their participation.

APPENDIX B. MODELLING DETAILS

B.1 Buildings

The two key drivers of change in energy demand for space and water heating will be the improvement of building stock energy efficiency, as well as the changing heating technology mix as Greater Manchester decarbonises until 2038. Natural gas is currently the key fuel for heating in the city-region as 96% of buildings in GM are connected to the gas grid, 2% have electric heating and the remaining 2% are heated by oil and coal. In the future, retrofitting existing buildings, the addition of new highly efficient buildings and the shift towards zero-carbon heating will reduce overall energy demand in buildings and change the heating fuel mix.

Existing buildings: Buildings which are not connected to the gas grid (4% of total) are expected to switch to purely electric heat pumps. Air- and ground-sourced heat pumps are very fuel-efficient, i.e. they require 60% less energy than a gas boiler to heat the same space. However, to ensure an optimal operation profile, electric heat pumps can only be installed in highly energy-efficient properties. Before heat pump installation, existing buildings will require “deep” intervention, e.g. underfloor insulation and heating or solid wall insulation cladding. Buildings that are extensively retrofitted are expected to see a reduction of energy demand by 54%. The combination of high fuel efficiency of heat pumps and the expected building efficiency gains result in a significant reduction in end energy demand in our analysis.

Grid-connected buildings will be heated either through hybrid heat systems or boilers fuelled by hydrogen. Hybrid heating systems are considered more economically attractive in buildings with an energy efficiency rating C and above. However, their installation requires space in the building. To account for spatial considerations, it was assumed that dwellings larger than $70m^2$ would have enough space to accommodate a hybrid heating system. The energy demand analysis considers the improved fuel efficiency of hybrid heating systems which on average use 19% less energy compared to gas boilers.

GM’s current building stock was assessed with regards to current building energy efficiency. The majority of buildings fall in the “medium” C and D categories, and domestic buildings are generally more efficient than non-domestic buildings.

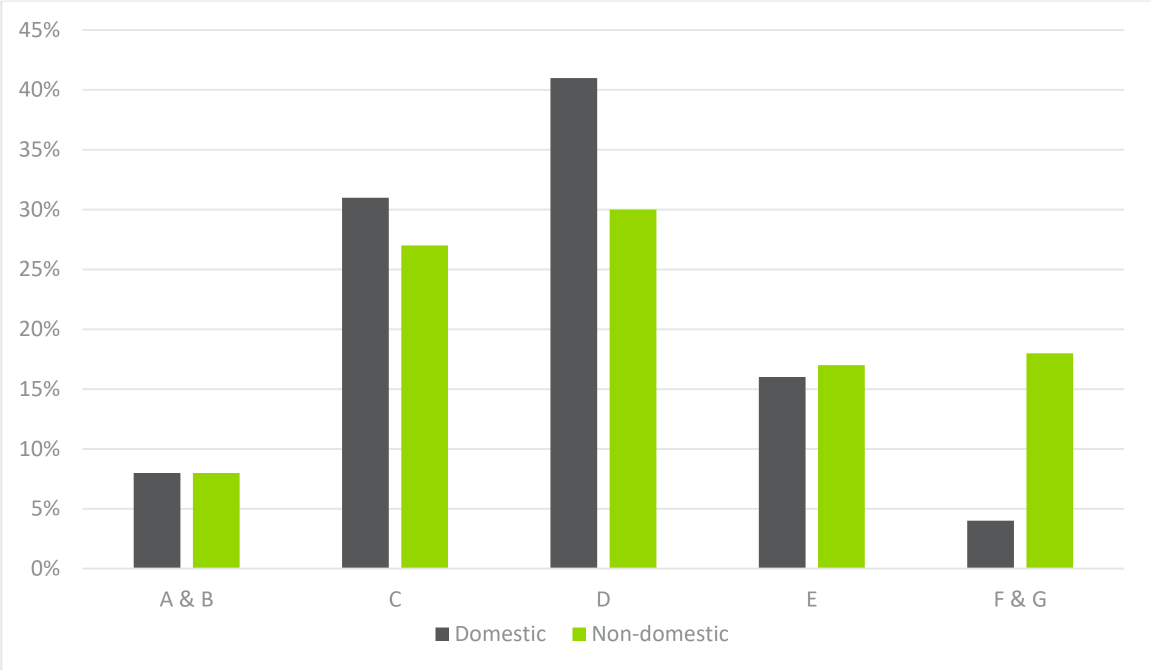


Figure 20: Current Energy Performance of Buildings in Greater Manchester

- *Residential buildings*: Buildings with a current EPC rating A to E can be upgraded to at least a C level. Among these, 61% of dwellings are larger than 70m^2 and are expected to switch to hybrid heating systems. Such heating systems should be complemented with moderate building renovation, e.g. high-performance glazing and loft insulation. These "shallow" building interventions are expected to yield a 21% energy efficiency gain which is reflected in the energy demand calculations. The remaining 39% of houses in the A to E category have a floor surface less than 70m^2 and are considered too small to install a hybrid heating system. These buildings together with properties which have a current EPC rating of F or G are expected to upgrade their boilers to hydrogen-ready boilers in the future and continue heating their home using just a boiler.

- *Commercial buildings*: Commercial buildings are typically large enough to accommodate a hybrid heating system and will be more responsive to the economic value of such heating systems. Hence, all grid-connected commercial buildings with current EPC rating E and above are expected to convert to a hybrid heating system. Commercial buildings with EPC rating F or G continue to use a gas boiler that will have to be hydrogen-ready in the future.

To account for building demolition, the analysis expects that existing buildings are demolished at an annual rate of 0.1% for residential buildings and 0.5% for commercial buildings.

New buildings: All new buildings are expected to be highly efficient at EPC rating A at which they can be heated with a fully electric heat pump. Three quarters of all new properties are expected to be heated in this way. New buildings being developed in densely populated areas might also be able to connect to a local heat network. However, given the currently low rate of heat network development, only a quarter of new developments are expected to be supplied by network heat.

B.2 Transport

Energy demand in the transport sector was assessed based on the expected distance travelled by different modes of transport used in 2038: cars, public transport (trams and buses), train, light commercial vehicles (LCV) and heavy goods vehicles (HGVs). We used a range of publicly available sources on current transport use and trends to estimate the number of vehicle-kilometres travelled. In our assessment we considered GM's ambition to reduce the share of daily journeys taken by car from 61% today to 50% by 2040 as laid out in the Transport 2040 strategy. Instead, GMCA hopes to increase the share of sustainable modes of transport: trains, public transport, walking and cycling. In 2038 total vehicle-kilometres travelled in GM adds up to 17.3 billion and is split as follows: cars (81%), LCV (14%), HGVs (4.5%), public transport (0.6%) and rail (0.1%).

In line with GM's Transport 2040 Strategy, all road transport is expected to be decarbonised and the fuel mix will vary by transport mode. In line with analysis done for the ENA, Navigant expects the following fuel mix in the transport sector:

Table 1: Transport modes in Greater Manchester, 2038

Mode of transport	Electricity	Hydrogen	Bio-LNG
Passenger cars	96%	4%	
Buses	85%	15%	
Trains/trams	100%		
LCVs	90%	10%	
HGVs	30%	50%	20%

Energy consumption by each mode of transport was calculated given the fuel split above and average fuel consumption for each type of technology.

B.3 Industry

The "industry" category includes energy for industrial heat consumption. In a first step, Navigant estimated the quantities of different energy carriers (natural gas, electricity, others) consumed in industry in GM today.

BEIS publishes data on energy consumption by sector and type of end use. Energy demand by industrial sector in GM was estimated by scaling available country-level demand data to the city-region level using Gross Value Added (GVA) as a proxy.

Table 2: Industrial sectors in Greater Manchester

Sector	Gross Value Added (GM as a share of Great Britain)
Food, beverages and tobacco	4.6%
Textiles, wearing apparel and leather	10.5%
Wood and paper products and printing	5.1%
Petroleum. Chemicals and pharmaceuticals	4.3%
Rubber, plastic and non-metallic minerals	5.2%
Basic and fabricated metal products	3.9%
Computer, electronic and optical products	3.7%
Electrical equipment	4.5%
Machinery and equipment	3.8%
Transport equipment	0.8%
Other manufacturing, repair and installation	3.4%
Mining and quarrying	0.2%

Industrial heat demand can be assigned to three categories: high temperature processes, low temperature processes and space heating. BEIS data on industrial energy consumption breaks down these industrial end uses by the underlying fuel mix:

Table 3: Industrial energy end use, by industrial process

Industrial end use	Natural Gas	Electricity	Other (oil, solid fuels)
High temperature processes	55%	23%	22%
Low temperature processes	65%	25%	10%
Space heating	54%	34%	12%

Provided the data above, it was possible to calculate how much natural gas, electricity and other fuels is currently consumed by industrial end use in GM. By 2038, industry is expected to become more energy efficient and switch to zero-carbon fuels as much as possible.

Navigant expects industrial process energy consumption to fall by 20% given on-going efficiency improvements in industrial processes. Furthermore, low temperature processes are expected to be electrified, i.e. natural gas as a fuel will be replaced by electricity. High temperature processes are technically more difficult and more costly to electrify due to the amount of required electricity and are expected to be converted from natural gas to hydrogen as a zero-carbon energy source.

Similarly, to the buildings sector, space heating in industry is expected to be converted to electricity or hydrogen due to the use of hydrogen-ready boiler and/or electric heat pumps. Energy demand for space heating is expected to increase as industrial space is projected to increase by 4.75 million m^2 by 2038.

B.4 Electricity (excl. heat or transport)

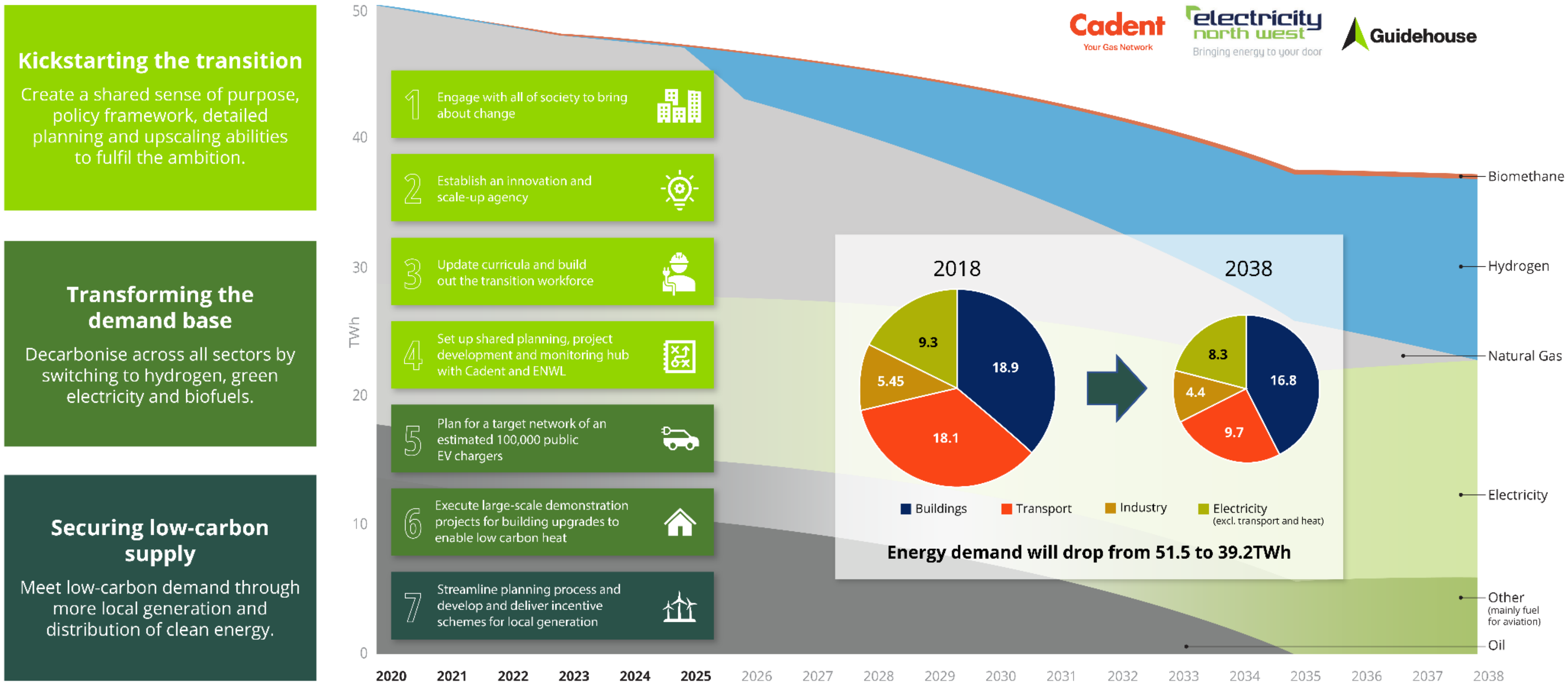
Electricity demand for use other than heating and transport was estimated separately. This is a sizeable category and includes electricity used for lighting, electric appliances, air conditioning, industrial processes (motor running, compressed air), etc.

Historically, electricity consumption has been gradually decreasing in the UK, and GM is no exception. Since 2010, electricity consumption in the industrial & commercial sector has been falling by 0.4% per year and in the domestic sector by 0.9%. This reduction is a result of improving energy efficiency among electricity users and Navigant expects this trend to continue through to 2038. Electricity demand was, therefore, extrapolated along this trend out to 2038.

APPENDIX C. PATHWAY INFOGRAPHIC

GREATER MANCHESTER DECARBONISATION PATHWAY TO 2038

Three tracks fuelled by **seven priority actions** for the Greater Manchester Combined Authority to start **transforming the energy demand and supply** now



APPENDIX D. LIST OF KEY ACTIONS

D.1 Kickstarting the Transition

Period	Key Actions	ID
2021-2025	GMCA should make its decarbonisation ambition an integral part of its identity, create a common sense of purpose elevating its profile as a leading, innovative and green region. To raise social awareness, the GMCA should develop a communication strategy including integrated branding, urban and on-line presence which clearly sets out the vision, explains the motivation and strategy. User-friendly learning resources should be prepared explaining the climate action GM's residents and businesses can take.	K1
2021-2025	GMCA should lead by example and decarbonise its own operations to build trust in the achievability of the 2038 target.	K2
2021-2025	GMCA should leverage the option of policy sandboxes where possible to generate momentum and inform future policy development, i.e. around building codes and local energy trading.	K3
2021-2025	GMCA should work closely with national stakeholders to monitor and influence the development and adoption of future-facing policy and regulation on hydrogen, CCS, heat and buildings.	K4
2021-2025	GMCA should collaborate with local higher educational institutions, establish an innovation and scale-up agency that helps mature mid-TRL (technology readiness level) products, services and supporting business models.	K5
2021-2025	GMCA should collaborate with Cadent and ENW, vocational schools, businesses and others to update curricula and provide internships to develop the skills and resource pool required for the net-zero ambition in an accelerated timeframe. To achieve the appropriate rate of building interventions, a dedicated workforce of around 20,000 trained contractors will be required by 2025. Digitalizing workflows can help achieve the required efficiency levels and execution speed.	K6
2021-2025	GMCA should lead the formation of a shared planning, monitoring and resource hub with Cadent and ENWL that provides data-driven insight into network capacity, spatial planning, tracks progress and can act as an advisory body for participants in the building, industry and transport sector on the nature and timing of interventions.	K7
2021-2025	GMCA should conduct a detailed building stock survey to prepare for large-scale renovation of the building stock. The results should be made publicly available. It is recommended to use existing data sources and platforms such as the EPC Rating database and Open Street Map for this. The building stock survey serves as a key resource for planning and tracking building interventions and monitoring their impact.	K8
2021-2025	Cadent, HyNet and National Grid should engage in detailed local gas network planning on the rollout of H2 to GM and the geological storage requirements that result from the transition to hydrogen. In parallel, Cadent, National Grid, HyNet and others should undertake detailed regional gas network planning to create a North of England Hydrogen Zone which will increase access to various sources of hydrogen, improve security of supply, broaden access to hydrogen storage.	K9
2026-2030	GMCA should coordinate with the Dept. of Transport, Cadent, National Grid, BEIS and others on the planning for the long-term supply of bio-methane (large scale AD and or Bio-SNG) for heavy road freight at key transport hubs (M6, M60, M61, M67 etc)	K10

D.2 Transforming the Demand Base

D.2.1 Buildings

Period	Key Actions	ID
2021-2025	• GMCA should design and enforce mandatory building codes, regulation and incentives for new and existing buildings with a view to net zero	D1
2021-2025	• GMCA should create an incentive scheme to promote uptake of hydrogen-ready boilers and cookers by homeowners	D2
2021-2025	• GMCA should work with the building sector to execute large-scale demonstration projects (1000+ homes) for building upgrades which include building insulation, low carbon heating systems and supporting hydrogen-ready devices (boilers, cookers etc.)	D3
2021-2025	• Cadent, ENW, energy retailers and energy service companies should pilot BEMS for in-building optimisation of energy usage	D4
2026-2030	• GMCA should enforce the requirement for new homes/buildings to be built to a standard that enables the use of all-electric heat pumps	D5
2026-2030	• GMCA should work with housing corporations and large investors owning commercial and residential properties to start the large-scale upgrading of the existing building stock, achieving a rate of 400 properties per day by 2030.	D6
2026-2030	• Cadent, ENW, energy retailers and energy service companies should start the deployment of B2G and V2G and other demand side management technologies (smart heating controls and IoT white goods etc.) for renewables integration and grid management	D7
2031-2035	• GMCA should work with installers, contractors and homeowner associations to expand the large-scale upgrading to include more challenging and difficult to reach parts of the building sector while maintaining a renovation rate of 400 properties per day.	D8
2031-2035	• Energy suppliers, appliance manufacturers and energy service companies should start converting hydrogen-ready devices to run fully on hydrogen where needed and applicable, as the natural gas grid gets converted street by street to a hydrogen grid.	D9
2031-2035	• Cadent, ENW, energy retailers and energy service companies should expand the use of demand side management technologies (smart heating controls and IoT white goods etc) to unlock more sources of flexibility in the residential and commercial domain	D10
2036-2040	• GMCA should work with the building and energy sector to complete the upgrading of the building stock and the roll-out of hydrogen-ready devices	D11
2036-2040	• Cadent, ENW, energy retailers and energy service companies should continue to switch hydrogen-ready devices over to 100% hydrogen as the grid conversion continues	D12

D.2.2 Transport

Period	Key Actions	ID
2021-2025	• GMCA and districts should implement the *Bee Network* - a walking and cycling network covering all Greater Manchester	D13
2021-2025	• GMCA should make use of available funding to create additional incentives for bus operators to start adopting battery-electric buses (and compare these to hydrogen-based alternatives)	D14
2021-2025	• GMCA needs to coordinate the selection of bus charging standards, identify locations for bus depots and coordinate with ENWL and bus operators the development of shared electric bus depots	D15
2021-2025	• GMCA needs to work with ENWL to plan for a target network of an estimated 100,000 public EV chargers throughout Greater Manchester. Implement incentives for charging network operators to install 19,000 public EV chargers by 2025	D16
2021-2025	• GMCA should work with the transport sector organisations to assess demand for charging/refuelling stations for heavy goods vehicles and identify key locations for station operators to invest in	D17
2026-2030	• GMCA should continue the stimulation of a shift to sustainable modes of public transport for both medium- (Bus Rapid Transit and Metrolink) and long-distance commuters (regional rail)	D18
2026-2030	• GMCA and ENWL should work with charging operators to expand the EV charging network beyond top-priority locations including residential areas to reach a network of 52,000 public EV chargers by 2030.	D19
2026-2030	• GMCA should work with bus operators to ensure that over half of the bus fleet is decarbonised to hydrogen or electricity by 2030.	D20
2031-2035	• GMCA should introduce a scrappage scheme for ICE vehicles and zero-emissions zone covering all forms of (light) road transport to meet the 2035 zero emission target	D21
2031-2035	• GMCA and ENWL should work with charging operators to complete the development of a public EV charging network and reach 100,000 public EV chargers by 2035.	D22
2031-2035	• GMCA should work with bus operators to ensure that the whole bus fleet is decarbonised by 2035.	D23
2036-2040	• GMCA should ensure the zero-emission zone effectively deters non-zero-emission heavy-duty vehicles from 2038 on, in order to reach its net zero carbon target	D24

D.2.3 Industry

Period	Key Actions	ID
2021-2025	GMCA should develop incentive schemes to encourage energy efficiency and fuel recycling in industrial processes	D25
2021-2025	Cadent and ENWL should work with industrial clusters to assess and select the most optimal decarbonisation options to maximize synergies and economies of scale in the use of energy	D26
2021-2025	ENWL should work with industrial facility owners and operators to start electrification of industry where technically feasible and lowest cost	D27
2026-2030	Cadent should plan and manage the supply of hydrogen from HyNet through a new dedicated network to supply industry	D28
2026-2030	Industrial equipment manufacturers and facility operators should prepare equipment (e.g. boilers) and industrial processes to be hydrogen-ready	D29
2026-2030	Industrial facility owners and operators should continue electrifying low-temperature processes as electrification costs decline	D30
2031-2035	Cadent should support the acceleration of hydrogen-switching in industry, coordinating and planning for effective mass adoption	D31
2031-2035	Industrial equipment manufacturers and facility operators should continue the replacement of equipment and decarbonisation of processes	D32
2036-2040	Cadent and industry should collaborate to capture remaining emissions produced within industrial clusters and utilize the carbon or transport for CO_2 storage	D33

D.3 Securing low-carbon supply

D.3.1 Electricity

Period	Key Actions	ID
2021-2025	GMCA should streamline and shorten planning permission processes, identify key development areas and develop incentive schemes to: • Expand the local uptake of rooftop solar PV to reach 200MW installed capacity by 2025 • Onshore wind development in Greater Manchester • Develop energy-from-waste and biomass plants	S1
2021-2025	• GMCA should stimulate collaboration between ENW, energy retailers, energy service companies and aggregators to trial Local Energy Markets for peer-to-peer trading of electricity	S2
2021-2025	• ENWL will expand the LV grid monitoring to assess impact of increasing loads from local generation, EV-uptake and electrification of heat by the end of Fiscal Year 2023.	S3
2026-2030	• The GMCA should continue incentivizing rooftop solar PV to ensure that around 360MW is installed by 2030	S4
2026-2030	• GMCA should work with the energy and building sector to collectively expand behind-the-meter storage for electricity and heat	S5
2026-2030	• ENW, energy retailers, energy service companies and aggregators should enable Local Energy Markets and Demand Response at scale • ENWL should prioritise targeted electricity network reinforcement to support demand electrification	S6
2031-2035	• GMCA should work with investors and residents to ensure that renewable electricity generation is nearing full potential by 2035, including 680MW rooftop solar	S7
2031-2035	• GMCA should assess options for offsetting the impact of National Grid imports	S8
2031-2035	• GMCA should coordinate with the energy sector for ongoing procurement of grid-connected smart solutions	S9
2031-2035	• ENWL should continue electricity network reinforcement to support demand electrification	S10
2036-2040	• GMCA should manage the impact of remaining carbon of electricity imports from National Grid	S11
2036-2040	• GMCA should work with Carrington CCGT to accelerate the conversion to low-carbon fuels before the end of the current turbines' full lifetime	S12
2036-2040	• ENWL should continue electricity network reinforcement to support demand electrification	S13

D.3.2 Hydrogen

	Key Actions	ID
2021-2025	GMCA should work with the HyNet consortium and Cadent to ensure timely supply of hydrogen to Greater Manchester and communicate regularly on changing energy requirements	S14
2026-2030	• GMCA should work with Cadent and industry to coordinate the switch of industrial users to hydrogen in a safe and timely manner, starting from Trafford Park	S15
	• GMCA should work with Cadent and industry to plan for appropriate hydrogen storage capacities required near the sites of anchor users	S16
2031-2035	• GMCA should ensure large-scale hydrogen storage is included in spatial planning activities	S17
	• GMCA, individual districts and the DNOs need to coordinate the switch of residential parts of the gas grid, including a broad communication campaign aimed at residential and commercial consumers	S18
2036-2040	• Cadent and gas suppliers should take advantage of increasingly cost-competitive green hydrogen opportunities by locating production closer to demand centres thereby avoiding the need for gas grid expansion or reinforcement	S19