UK Biomass Resource Availability for the Glass Sector

UK Biomass Resource Availability for the Glass Sector:

Exploring the Feasibility of Decarbonising the UK Glass Sector through Bioenergy

Technical Report for Glass Futures

Project Team

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Bioenergy Expertise

1.1. Tyndall Centre Bioenergy Research & Expertise

Tyndall Manchester is a vibrant and committed research community that brings together natural scientists, engineers, social scientists and economists to produce socially impactful and policy-relevant interdisciplinary research.

As a group we have over a decade of experience in undertaking genuinely interdisciplinary approaches to complex policy problems. Our holistic approach remains a national and international benchmark in climate change mitigation and adaptation research. We have ongoing research on energy systems, carbon budgets and pathways, the water energy food nexus, communities, and circular economy.

Tyndall Manchester carries out research on all stages of bioenergy supply chains and systems. This includes how biomass resources are grown and sourced, the conversion technologies for producing energy and bio-products, through to the wider socio-economic and environmental performance, whole system assessments, policy analyses and global challenges.

We actively collaborate with industry, government, and international stakeholders to ensure that bioenergy can provide low carbon energy pathways and mechanisms for achieving sustainable development. Our work is carried out as part of the UK's Supergen Bioenergy Hub network.

1.2. UK's Supergen Bioenergy Hub

The Supergen Bioenergy Hub works with academia, industry, government and societal stakeholders to develop sustainable bioenergy systems that support the UK's transition to an affordable, resilient, low-carbon energy future. The Hub is funded jointly by the Engineering and Physical Sciences Research Council (EPSRC) and the Biotechnology and Biological Sciences Research Council (BBSRC) and is part of the wider Supergen Programme.

The vision of the Supergen Bioenergy Hub is to enable and stimulate the development of a sustainable UK bioenergy sector. This is supported through the Hub's whole-system research approach that encompasses all aspects of bioenergy expertise to identify pathways for delivering bioenergy with wider social, economic and environmental benefits. The Hub's research also includes the development of innovative bioenergy technologies through the different technology readiness levels (TRLs) in order to deliver cost-effective, efficient and sustainable energy. In this way, UK academics support policy and industry in identifying and characterising sustainable bioenergy systems that can be prioritised to provide power, heat, liquid and gaseous fuels, and value-added chemicals.

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1. Introduction

In 2019 the UK became the first major economy to legislate a binding target to reach net zero emissions by 2050. To achieve this, all sectors of the economy need to review their operations, develop strategies and implement actions to reduce emissions from their activities. With industry representing nearly a quarter of UK emissions the decarbonisation of industrial activities will be essential for meeting climate change targets. Decarbonisation will be achieved through a combination of improving energy efficiency, updating practices and greater utilisation of low carbon energy technologies and fuels. In turn the decarbonisation of industry will be an essential driver for reducing business energy costs, improving industrial productivity and competitiveness, and driving clean economic growth [1].

The UK glass sector is currently a significant contributor to the UK's industry emissions. The manufacturing of glass is an energy intensive process, requiring high temperatures to melt the constituent raw materials of glass including sand and limestone. Furnaces account around 85% of energy use and predominantly use natural gas to generate the required heat. Electricity is used to run other equipment and sometimes to supplement the furnace. For the glass sector to decarbonise and contribute to the UK's net zero targets, alternative sources of low carbon energy and/ fuels will be required to balance the significant demands of glass furnaces [2].

The research presented in this report has been developed to investigate the feasibility biofuels providing a low carbon alternative energy option for the glass sector. The research's focus is to identify the opportunities and constraints of UK waste and residue biomass resources that may be mobilised to to provide biofuels for the UK glass sector. This report presents research that:

- Identifies the key categories of UK biomass resource that may be available for future bioenergy sector.
- Identifies the regional biomass resource opportunities in the UK, highlighting the leading biomass resources potentially available within given radii of key UK glass manufacturing sites and regions.
- Identifies optimal centralised locations for liquid biofuel production for glass furnaces, given the spatial availability of UK biomass resources and the locations of leading UK glass manufacturing sites.

1.1. Our Understanding of the UK Glass Sector

The UK glass sector produces over 3 million tonnes of glass per year that provides an essential component of the supply chains of many wider manufacturing sectors including food and drink, construction, renewable energy and the automotive sector. Of these, container glass products such as bottles and jars account for around 60% of all UK glass production. Glazing products for the construction and automotive sectors account a further 30%, with the remaining 10% of manufactured glass is used to produce fibreglass and specialist products for lighting, oven hobs, medical applications etc [2].

The glass sector is highly dependent on industry trends that influence their primary customers. For example, in the container glass sector long term use of glass will depend on the continued ability of bottle and jar manufacturers to remain competitive with alternative emerging packaging materials. There are also key growth sectors where demand for glass products are likely to increase including within wind energy, electronics and fibreglass applications [3].

High-volume glass manufacturing contributes around £1.3 billion to the UK economy each year [4]. The sector supports around 6,000 people, maintaining a large number of direct and indirect jobs in downstream sectors including construction, packaging, wind turbine manufacturing and lab and scientific equipment [5].

1.1.1. Key UK Glass Manufacturing Sites

The sector is concentrated in the North East and North West of England and Scotland, and consists several large manufacturers and a number of smaller specialist companies [5]. Figure 1 maps a number of the key UK glass manufacturing sites in Great Britain identified following consultation with Glass Futures, and are the focus of analyses presented in this report.

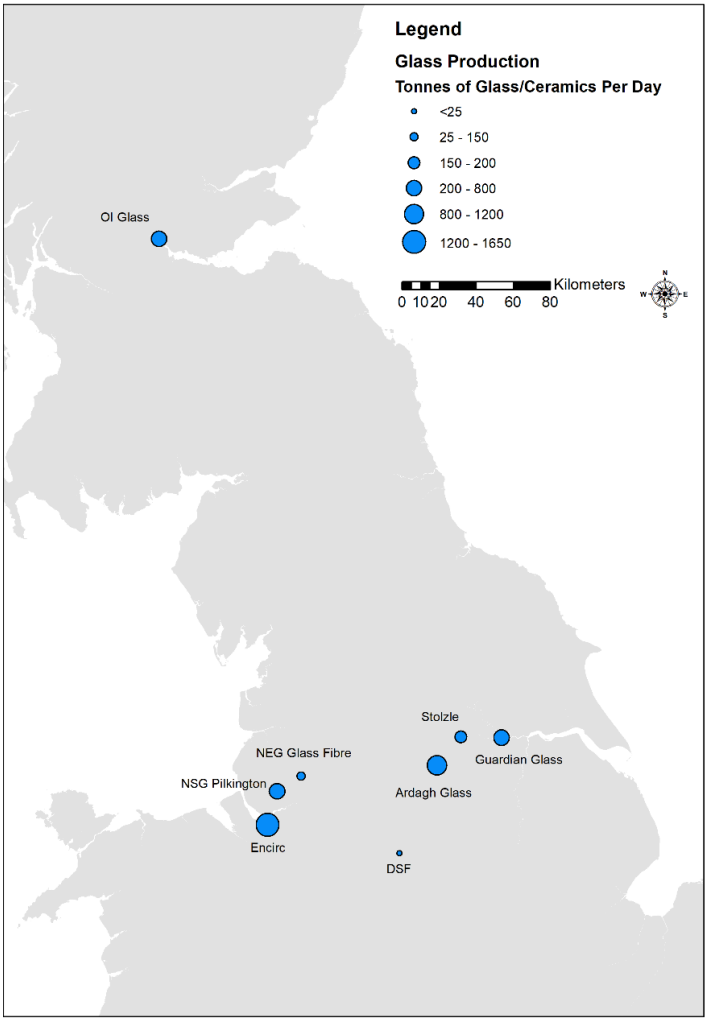

Figure 1: Location & Comparative Scale of the UK Glass Industry Sites included in this Biomass Resource Feasibility Study

2. UK Biomass Resources for the Bioenergy Sector

The following section identifies the key categories of UK biomass resource that may be available for the future bioenergy sector. Presenting ranges of UK waste and residue biomass resource availability as reflected in existing literature.

2.1. UK Availability of Wastes & Residues

There have been many previous studies that have completed resource modelling exercises to forecast the levels of UK biomass resource that may be available to the future bioenergy sector. Figure 2 supported by Table 1 documents the ranges of biomass resource availability by 2030 as forecasted by a number of such studies [6–19]. The size of the range between the min and max estimates, potentially represents variations in how much resource may be generated and/ or the extent that available biomass may be available for the bioenergy sector according to the different studies. Where there is a narrow range between the min and max estimates, there is greater consensus across the different studies in how much resource is potentially available. The scale of the maximum estimated values may also provide an indication of the scale action that may be required to mobilise upper limits of available resource [10].

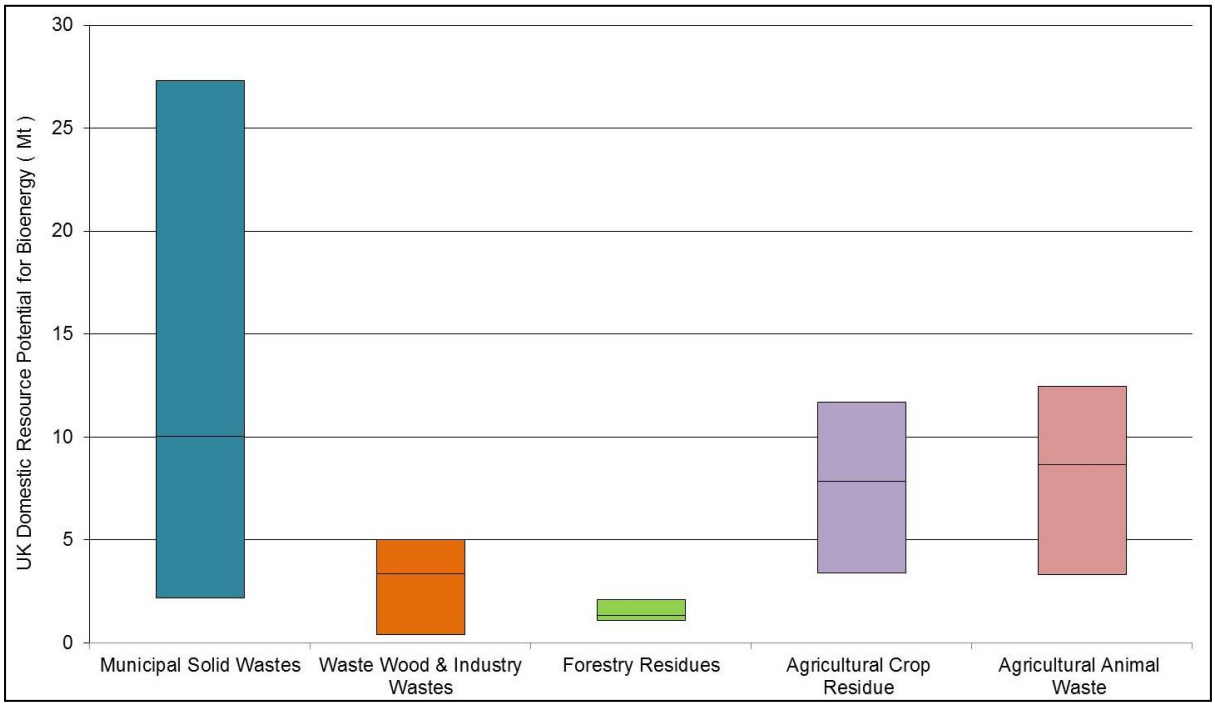

Figure 2: Ranges of UK Biomass Resource Availability for the Bioenergy Sector by 2030 [6–19]

Table 1: Ranges of UK Biomass Resource Availability for the Bioenergy Sector by 2030 [6–19]

UK Biomass Feedstock Category	UK Biomass Resource Availability Forecasts within Studies (Mt)		
	Lowest Forecast	Mean Value	Highest Forecast
Municipal Solid Wastes	*2.20*	*10.02*	*27.31*
Waste Wood & Industry Wastes	*0.40*	*3.34*	*5.00*
Forestry Residues	*1.09*	*1.32*	*2.10*
Agricultural Crop Residues	*3.40*	*7.86*	*11.70*
Agricultural Animal Wastes	*3.30*	*8.65*	*12.45*

The largest biomass resource opportunities in the UK are shown to be potentially provided by MSW and from agricultural sources. The large differences between the upper and lower limits for the MSW forecasts suggests there are strong dynamics influencing whether this resource may be available or not. MSW biomass resource potentially only being available for bioenergy where there is a complementary waste management strategy [10]. The narrower ranges for the agricultural, industry and forestry resources suggests there is greater consensus across the literature in the estimated scales of resource that may be available for the bioenergy sector.

2.2. Potential Biomass Resource Opportunities for the UK Glass Sector

The following sections summarise categories of UK biomass resource that could provide sustainable feedstock opportunities for the glass sector. Focusing on waste and residue materials from the UK agricultural sector, from industry and people.

2.2.1. UK Agricultural Wastes & Residues

2.2.1.1. Potato Waste

In the UK 142,000 ha of land (2020) are dedicated for potato production, predominantly in East Anglia, Lincolnshire and Yorkshire [20]. Annually the UK produces 5.5Mt of potatoes and 12-20% of this volume is classified as potato waste materials generated as a by-product [21]. Potato processing generates peels, pulp and rejects that can be processed and incorporated into animal feed formulations, used as fertiliser or as feedstocks to generate bioenergy and fuels.

UK Commodity Production (2020)	Waste & Residue (%)	Indicative Availability for Bioenergy (%) [22]	Indicative Energy Content (HHV) [23]
5.5 Mt	*12-20%*	*0.36*	*16.33 MJ/Kg*

2.2.1.2. Sugar Beet Pulp

The UK dedicates 111,000 ha of land (2020) to the production of sugar beet, producing 5.98 Mt predominantly in East Anglia, Yorkshire and the East Midlands [20]. Growers deliver sugar beet to four British Sugar factories located in Cantley (Norfolk Broads), Bury St Edmunds (Suffolk), Wissington (Norfolk Fen) and Newark (Nottinghamshire). Sugar beet typically consists 75% water, 20% sugar and 5% beet pulp [24]. The pulp contains 80 to 94% fermentable components (pentosans, pectins, and cellulose) and only 12 to 16% lignin, crude protein and mineral substances – therefore may be a potentially attractive feedstock for bioenergy [25]. The main competing uses for sugar beet pulp are within animal feed for ruminants and to replace significant quantities of cereals in concentrate mixtures for dairy cattle.

UK Production (2020)	Pulp (%)	Indicative Availability for Bioenergy (%)[22]	Indicative Energy Content (HHV) [23]
5.98 Mt	*5%*	*0.18*	*17.83 MJ/Kg*

2.2.1.3. Straw Residues.

The crop agricultural sector generates large quantities of residue and waste material. For every tonne of food commodity produced there will be a corresponding volume of residue material generated such as straws that sometimes have alternative uses but may also represent a significant feedstock opportunity for the bioenergy sector [8]. The UK produces a wide range of cereal, sugar and oil-based crops across the various regions, the choice of crops depending on local conditions that determine productivity. Large volume of straw residue are produced each year with much of the material being used within wider agricultural process, such as for animal bedding or feed. Surplus straw is typically integrated back into soils to maintain soil organic matter. A growing number of studies suggest sustainable volumes of straw residue may be mobilised for the bioenergy sector without impacting the sustainability of the land or existing agricultural processes [6]. Straw may represent a significant feedstock opportunity for bioenergy where it can be used locally or where the straw is converted to high density fuels such as pellets, briquettes or advanced fuels [26].

Food Commodity	UK Land Dedication (2020) [20]	UK Production (2020) [20]	Straw (Residue-to-Product-Ratio) [27,28]	Indicative Availability for Bioenergy (%) [22]	Indicative Energy Content (HHV) (MJ/Kg) [29]
Corn (Maize)	*197,000 ha*	*0.03 Mt*	*1.9*	*0.09*	*19.08*
Oats	*210,000 ha*	*1.03 Mt*	*1.8*	*0.28*	*19.88*
Wheat	*1,387,000 ha*	*9.66 Mt*	*1.6*	*0.28*	*19.52*
Barley	*1,388,000 ha*	*8.12 Mt*	*1.4*	*0.28*	*21.26*
Rapeseed	*380,000 ha*	*1.04 Mt*	*2.0*	*0.09*	*19.31*
Pea	*51,600 ha*	*0.16 Mt*	*3.6*	*0.09*	*19.20*

2.2.1.4. Animal Manure

Animal husbandry and livery is widely practiced across all regions of the UK. Each year significant numbers of cattle, pigs, sheep, horses and poultry generate large quantities of manure waste that could provide opportunities for the bioenergy sector. The quantities of waste produced and potentially collected will be determined by the number of livestock and the methods in which they are housed and managed [10]. Existing uses for manures are mainly limited to applications as fertilisers, although excessive use can also lead to emissions and sustainability risks [26]. Agricultural manures therefore represent a leading opportunity for the bioenergy sector where they can be used locally or converted to advanced fuels, such as biogas generated through anaerobic digestion technologies.

Livestock	Head ('000 in 2020) [20]	Indicative Manure Factor (tonne/animal/year) [30,31]	Indicative Availability for Bioenergy (%) [22]	Indicative Energy Content (HHV) (MJ/Kg) [29]
Cattle	*9,615*	*6.56*	*0.53*	*21.66*
Pig	*5,148*	*0.78*	*0.19*	*20.07*
Sheep	*32,697*	*0.25*	*0.33*	*20.25*
Horse	*419*	*8.26*	*0.29*	*27.69*
Chicken	*172,000*	*0.04*	*0.28*	*19.40*

2.2.2. UK Industry Wastes & Residues

2.2.2.1. Municipal Solid Waste (MSW)

MSW is everyday waste that is discarded by the public. Wastes in the UK are managed by the waste hierarchy where the priority is to reduce, reuse and recycle waste before considering energy recovery options. In 2020 UK households generated 27 Mt waste of which 12.6 Mt was sent to landfill [32]. Utilisation of the organic wastes that are currently sent to landfill wastes should be a priority for the bioenergy sector as may represent a significant resource opportunity and its use may mitigate potentially high counterfactual emissions and environmental impacts [26]. The success of any energy/ biofuel from waste scheme will be dependent on the implementation of a complementary waste management strategy [10].

MSW	Non-Hazardous Waste (2018) (Mt/year) [32]	Energy Recovery (% in 2018) [32]	Landfill (% in 2018) [32]	Indicative Availability for Bioenergy (%) [22]	Indicative Energy Content (HHV) (MJ/Kg) [29]
Paper & Card	*2.69*	*0.47*	*0.33*	*0.34*	*21.18*
Wood	*0.88*			*0.56*	*20.31*
Food	*0.64*			*0.43*	*21.74*

2.2.2.2. Industry Waste

UK industry generates large quantities of waste materials. Leading categories of non-hazardous industry wastes that may represent significant opportunities for the bioenergy sector include paper and carboard, wood, textiles, food and garden/vegetal wastes – in 2018 the UK generated 13 Mt of these wastes of which >300,000 tonnes were sent to landfill [32]. As all wastes can be highly variable in their characteristics, their use in bioenergy applications will likely require pre-treatment processing prior to combustion or conversion into advanced biofuels [33].

Industry Waste	Non-Hazardous Waste (2018) (Mt/year) [32]	Energy Recovery (% in 2018) [32]	Landfill (% in 2018) [32]	Indicative Availability for Bioenergy (%) [22]	Indicative Energy Content (HHV) (MJ/Kg) [29]
Paper & Card	*5.55*	*0.07*	*0.09*	*1.0*	*21.18*
Wood	*3.12*	*17.44*	*3.56*	*1.0*	*20.31*
Textiles	*0.01*	*0.01*	*10.50*	*1.0*	*19.62*
Food	*3.11*	*0.01*	*3.92*	*1.0*	*21.74*
Garden	*1.73*	*0.15*	*5.45*	*1.0*	*20.32*

2.2.2.3. Sewage Waste

Levels of sewage wastes generated and potentially usable as a feedstock is dependent on the population and the design and coverage of sewage infrastructure [34]. In the UK 98% of rural and urban households are connected to the UK's sewage service infrastructure. Bioenergy/ biogas potentially being generated at the sites where sewage is processed – including >7,000 sewage treatment works in England and Wales and >10,000 works/ community septic tanks in Scotland and Northern Ireland [35].

Waste (2020) (Mt/year) [8]	Connectivity to Sewage Network [35]	Indicative Availability for Bioenergy (%) [22]	Indicative Energy Content (HHV) (MJ/Kg) [29]
>1.7	0.98	0.58	22.78

2.2.2.4. Forestry Residues

Residue material from the forestry sector represents a potentially attractive resource opportunity for the bioenergy sector, particularly in regions with forestry activity such as mills. In 2020 UK sawmills produced 2.9 million m^3 of softwood products in addition to 2.8 Mt of by-produce residues (chips, barks, sawdust etc.). Typically 20% of residue materials are sold to the bioenergy sector such as pellet manufacturers [36].

Residue Resource from UK Mills (Mt/year) [36]	Indicative Residue used for Energy end Uses (%) [36]	Indicative Availability for Bioenergy (%) [22]	Indicative Energy Content (HHV) (MJ/Kg) [29]
2.80	0.20	0.52	21.17

2.3. Biofuel Production Pathways

Biofuels represent such an attractive renewable alternative for option for many sectors as they may provide a sustainable low carbon drop-in alternative to conventional fossil fuels [37]. There is a vast array of bioenergy and chemical conversion processes and technologies available that may be applied to convert a wide range of biomass resource feedstocks into chosen biofuel [33]. Figure 3 present some of the available technologies and pathways for potentially converting the feedstocks introduced in Section 2.2 into drop-in biofuels for the glass sector.

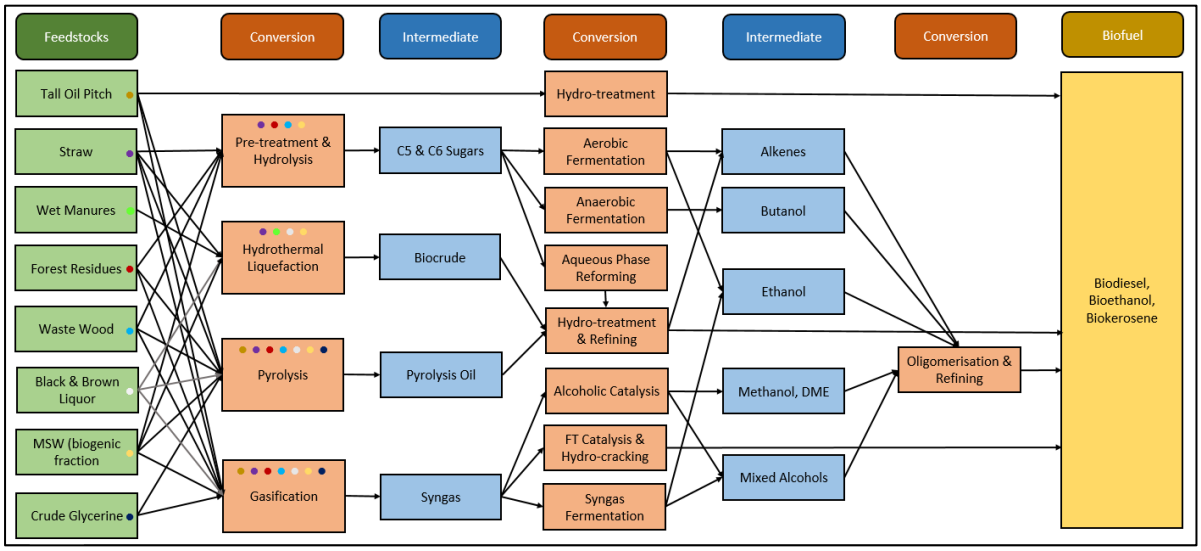

Figure 3: Potential Biofuel Production Pathways from UK Biomass Resources

3. Biomass Modelling – Opportunities for the Glass Sector

3.1. Modelling Approach

This research applies the University of Manchester's 'Biomass Resource Repository' (BRR) and 'Carbon Navigation System' (CNS) to analyse the potential availability of waste and residue biomass resource within given radii of key UK glass manufacturing sites. The BRR is a high-resolution biomass repository built using remote sensing and GIS maps to assess the spatial distribution and quantities of biomass across the UK down to the plot of land resolution. The categories of biomass resource assessed in this research are listed in Table 2.

The CNS model is a 'carbon-efficient digital twin' of the UK's industrial freight transport network for cargo and tanker transportation. The CNS model simulates and calculates the spatially explicit supply chain transportation emissions of specific biomass supply chains to generate high spatial resolution biomass availability estimates for given sites. Further details of the BRR and CNS model methodologies are presented in Freer et al (2021) [22] and wider examples of their application can be found externally [38,39].

Table 2: UK Waste Biomass Resources Assessed

Biomass Category	UK Feedstocks		
Agricultural Crop Residues	○ *Potato Waste* ○ *Sugar Beet Pulp* ○ *Corn/ Maize Straw* ○ *Winter Oat Straw*	○ *Spring Wheat Straw* ○ *Winter Wheat Straw* ○ *Spring Barley Straw*	○ *Winter Barley Straw* ○ *Rapeseed Straw* ○ *Pea Straw*
Agricultural Animal Wastes	○ *Cattle Manure* ○ *Horse Manure*	○ *Pig Manure* ○ *Sheep Manure*	○ *Chicken Litter*
Industry Wastes	○ *MSW (Paper, Wood, Food)* ○ *Garden Waste* ○ *Industry Paper*	○ *Industry Card* ○ *Industry Wood* ○ *Industry Textiles*	○ *Industry Food Waste* ○ *Sewage Sludge* *Forestry Residues*

3.2. Research Case Studies

Analysis focuses on three case studies developed through collaboration with Glass Futures. These are designed to highlight the types and quantities of biomass resource that may represent the leading opportunities for the glass sector in the UK regions where glass manufacturing is concentrated.

- **Single Site Case Study** – Focusing on the large OI glass manufacturing site in Scotland, this case study analyses the biomass resource opportunities within 50km of the Alloa site.
- **North West Glass Cluster** – focusing on the large glass manufacturing sites within the North West region of England, this case study identifies the optimal location for a potential centralised biofuel production site that could provide liquid biofuels for all sites within the cluster. Analysis identifies the biomass resource opportunities within 100km of a centralised North West facility.
- **Humber Glass Cluster** – focusing on the large glass manufacturing sites within the Humber region of England, this case study identifies the optimal location for a potential centralised biofuel production site that could provide liquid biofuels for all sites within the cluster. Analysis identifies the biomass resource opportunities within 100km of a centralised Humber facility.

3.2.1. OI Glass, Alloa – Single Site Case Study

Figure 4 highlights the location of the OI Glass site in Alloa in Clackmannanshire in the Central Lowlands of Scotland. Also, the search radii up to 50km from the site at 10km intervals – the research calculates the potential availability of biomass resources within each radii.

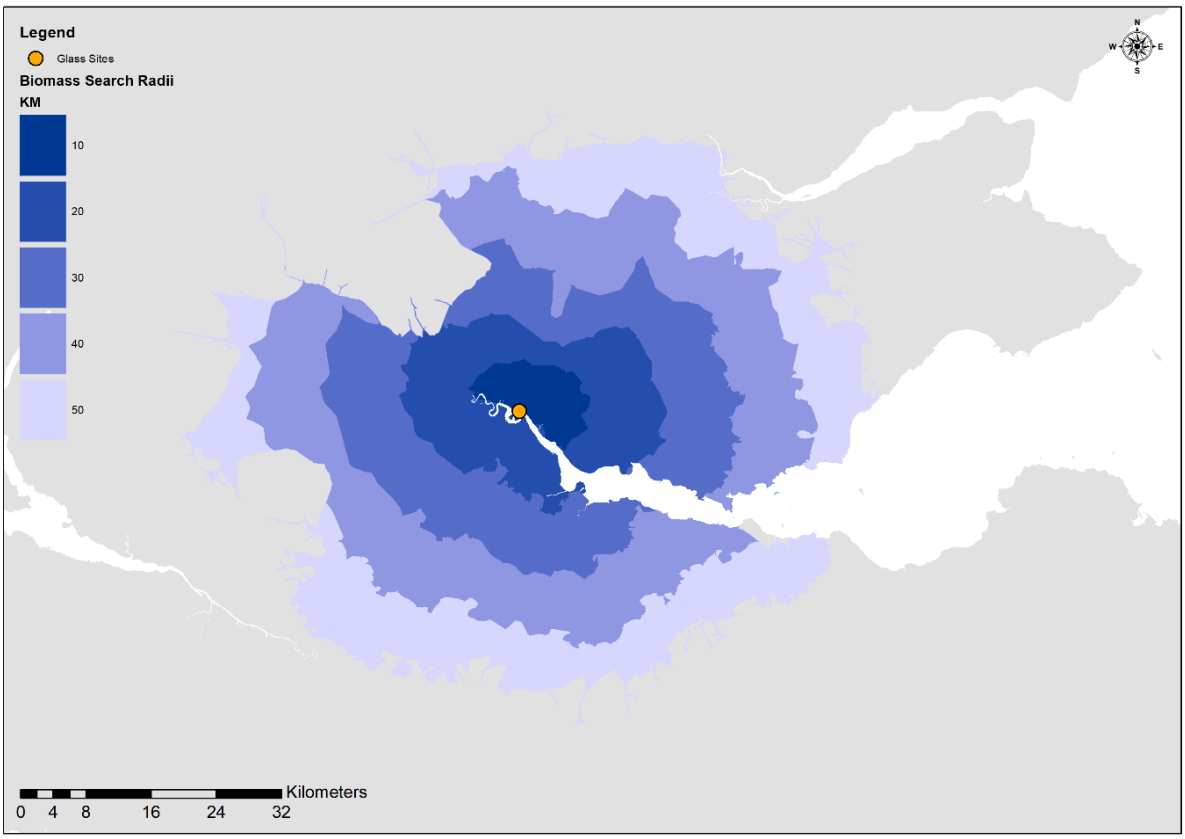

Figure 4: OI Glass, Biomass Resource Availability Search Radii. Mapping the location of the Alloa site and the 10, 20, 30, 40 and 50 km search zones.

3.2.2. North West Glass Cluster Case Study

Figure 5 presents three maps that characterise the North West cluster which comprises Encirc Glass in Elton, Nippon Electric Glass Fiber UK Ltd in Wigan and Pilkington Glass in St. Helens. Map A is a heat map that presents the locations of the sites and highlights the optimal zones for potential siting of a centralised bioenergy facility that could produce liquid biofuels servicing each site. The heat map zones are calculated accounting the relative energy demands of each site and the spatial distribution of resource potentially available within the region. Map B highlights the calculated optimal location for a centralised facility, potentially near Helsby in Cheshire. Map C presents the search radii up to 100km from this site at 10km intervals – the research calculates the potential availability of biomass resource within each radii.

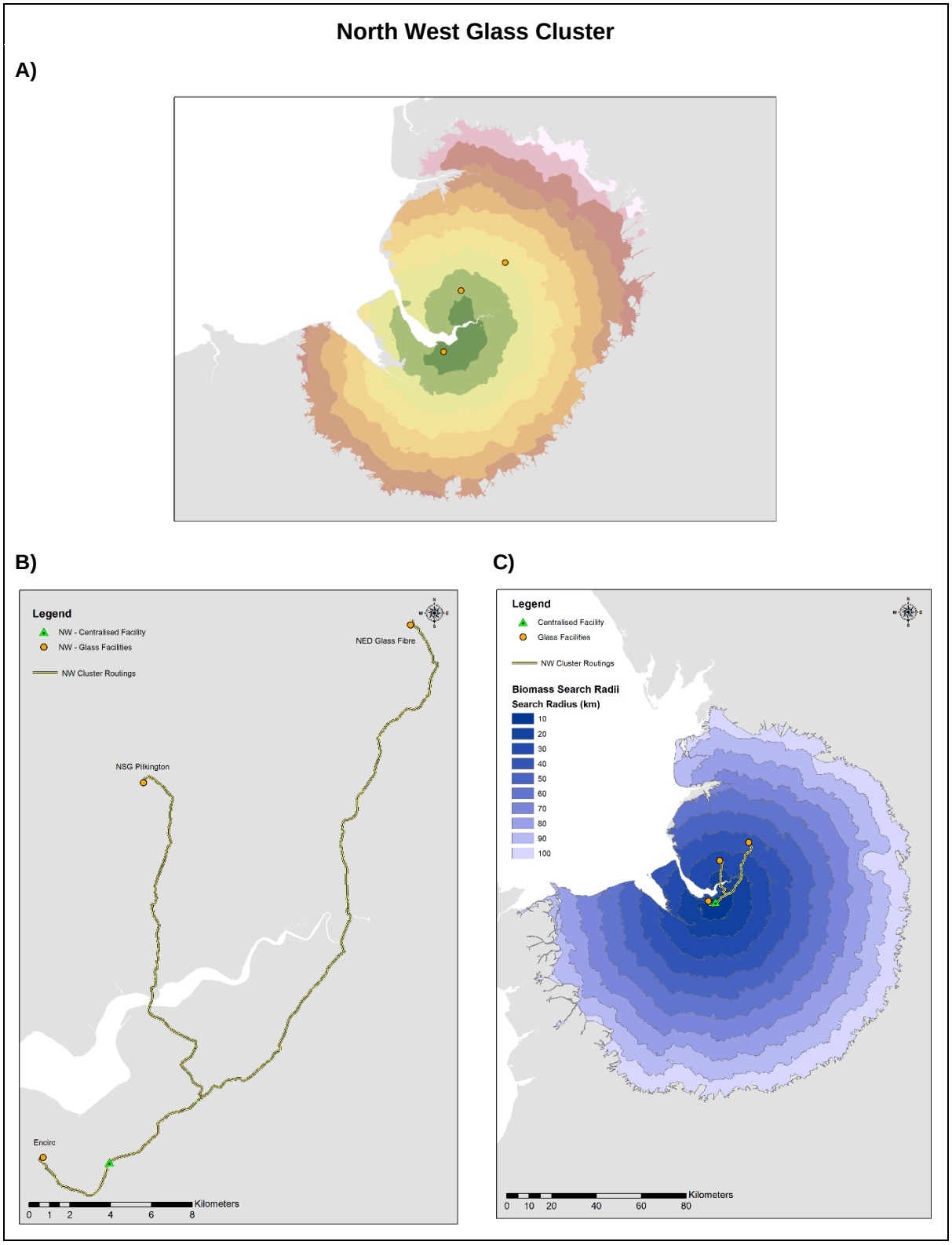

Figure 5: North West Cluster Maps. A) Optimal location zones for a centralised liquid biofuel production plant based on energy demands of key glass industry sites and available resource. B) Calculated optimal site for a North West biofuel production site servicing the North West glass industry. C) 10km biomass resource search zones radiating up to 100km from the optimal North West biofuel production site.

3.2.3. Humber Glass Cluster Case Study

Figure 6 presents three maps that characterise the Humber cluster which comprises Ardagh Glass in Barnsley, Guardian Glass in Goole and Stoelzle Flaconnage Ltd in Knottingley. Map A is a heat map that presents the locations of the sites and highlights the optimal zones for potential siting of a centralised bioenergy facility that could produce liquid biofuels servicing each site. The heat map zones are calculated accounting the relative energy demands of each site and the spatial distribution of resource potentially available within the region. Map B highlights the calculated optimal location for a centralised facility, potentially near Shafton in South Yorkshire. Map C presents the search radii up to 100km from this site at 10km intervals – the research modelling calculates the potential availability of biomass resource within each radii.

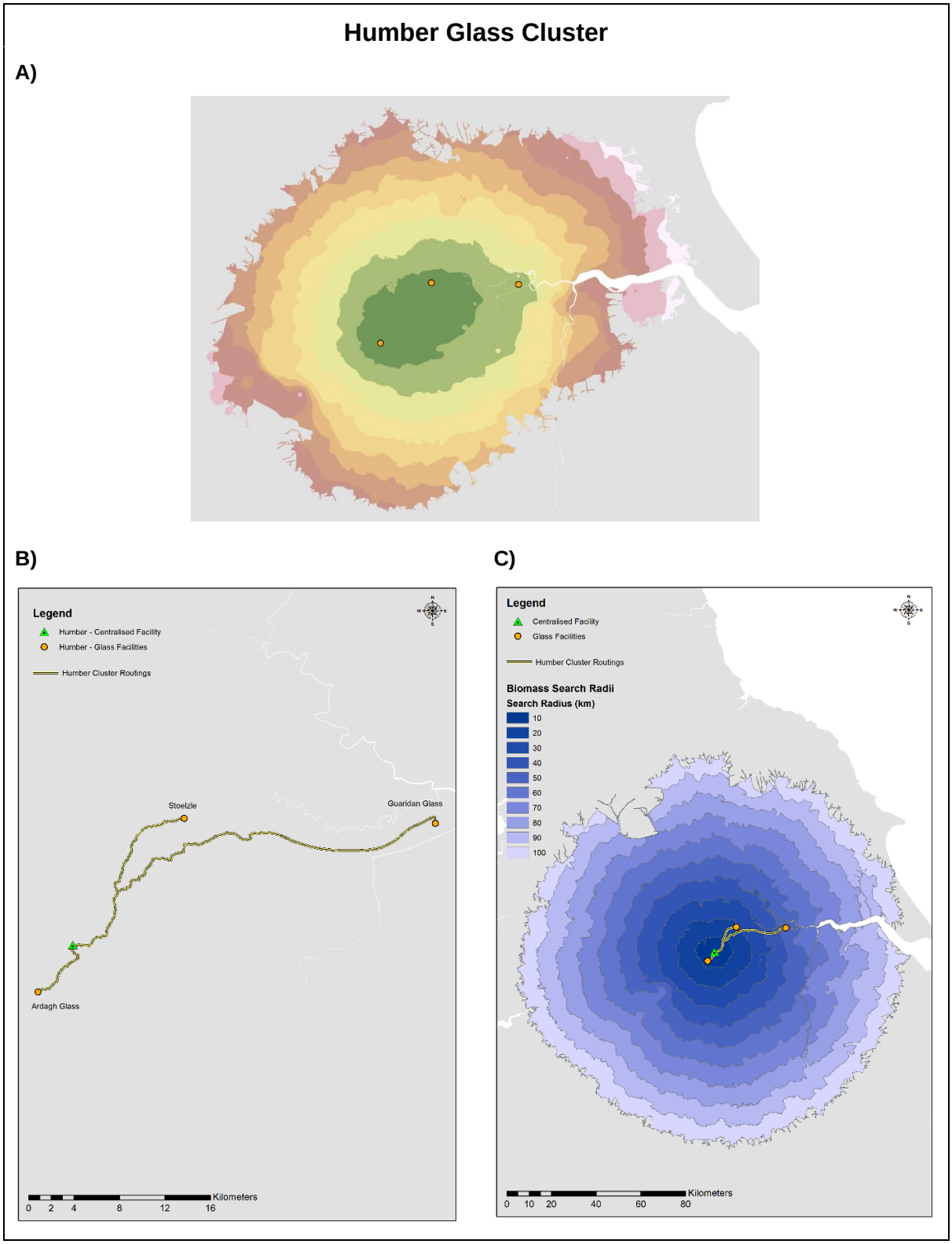

Figure 6: Humber Cluster Maps. A) Optimal location zones for a centralised liquid biofuel production plant based on energy demands of key glass industry sites and available resource. B) Calculated optimal site for a Humber biofuel production site servicing the Humber glass industry. C) 10km biomass resource search zones radiating up to 100km from the optimal Humber biofuel production site.

4. Resource Modelling Results

The following section presents the results from the resource modelling, calculating the potential availability of different categories of biomass within the 50km/100km search radius of each glass manufacturing site. The stacked bar charts provide a breakdown of the different resources included in the assessment. The line graphs presented on the second axis provide an indication of the levels of energy potentially available from crop resides and animal wastes in Graph A and industry wastes, sewage sludge and forestry residues in Graph B.

4.1. OI Glass, Alloa – Biomass Resource Availability

The results of the resource modelling for the OI Glass site in Alloa are presented in Figure 7 supported by the data included in the Appendix. Graph A presents the calculated potential available agricultural waste and residue resources at 10 km intervals up to 50km from the site, Graph B presents the calculated availability of industry residues.

- The research finds there are limited resource opportunities within the near vicinity of the Alloa site (up to 10km) although there are potentially significant opportunities within a 50km radius, particularly beyond 30km.
- There is larger resource and energy potential sourced from animal wastes biomass than crop residues. Wastes from cattle and sheep farming representing the largest agricultural resource opportunities, potentially over 150 and 128 thousand tonnes respectively within a 50km radius of the site.
- The leading crop residue biomass are wastes from potato production and processing and straw from wheat and barley, potentially providing over to 20 and 27 thousand tonnes respectively within a 50km radius of the site.
- The research finds residues from forestry industry activities potentially provides the largest single resource opportunity for the Alloa site. Forestry residues increase in availability particularly beyond 30km, potentially providing over 960 thousand tonnes within a 50 km radius of the site.
- Wider categories of MSW and industry wastes may collectively provide an attractive opportunity for the bioenergy sector, particularly from paper, card and wood resources that may currently be sent to landfill.

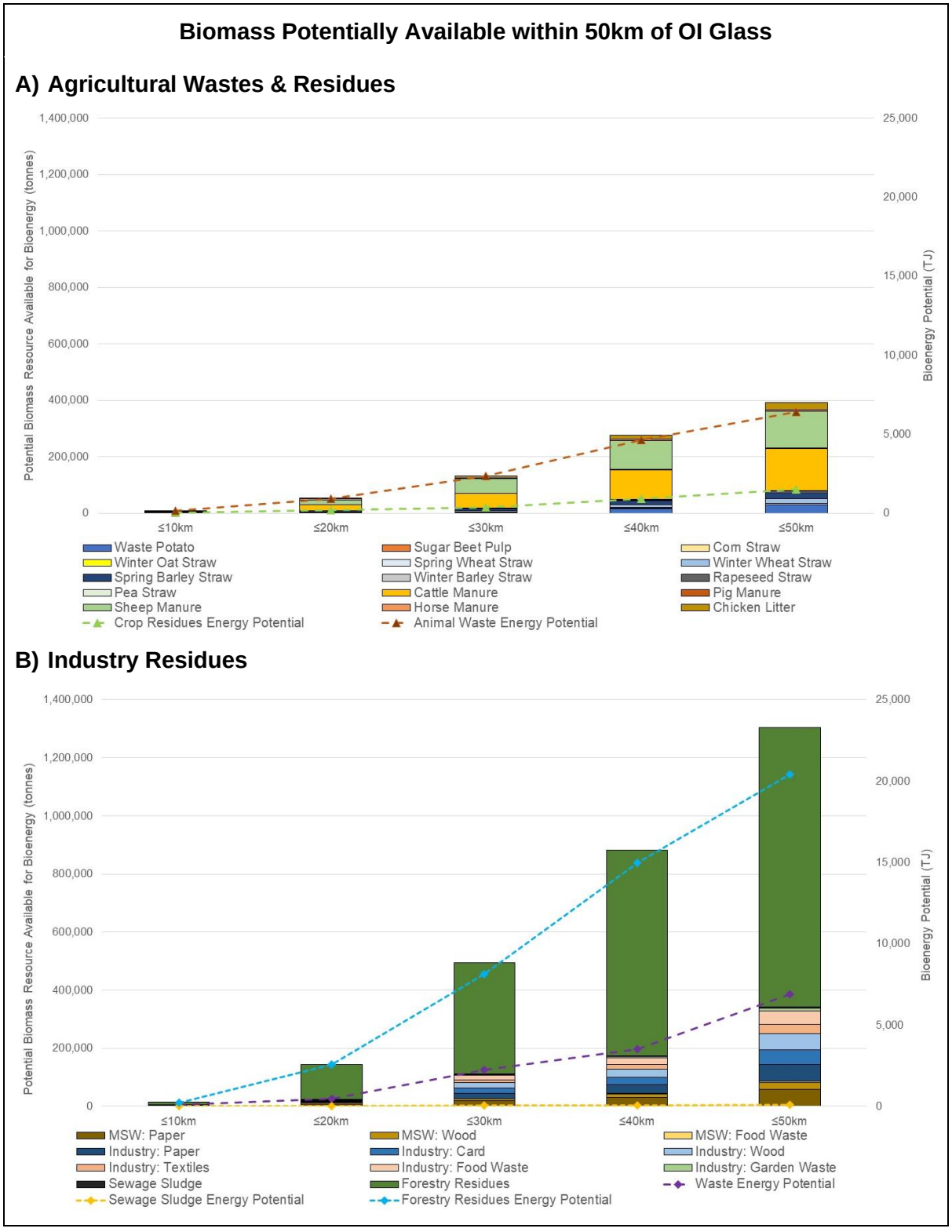

Figure 7: Biomass Resource & Bioenergy Potential Estimates for the OI Glass Site. Cumulative biomass resource potential estimates (tonnes) at ≤10, ≤20, ≤30, ≤40 and ≤50km from the Alloa site. Bioenergy potential estimates (TJ), indicating the total energy potentially generated given feedstock availability (tonnes) and calorific values (MJ/Kg, Section 2.2).

4.2. North West Cluster - Biomass Resource Availability

The results of the resource modelling for the North West cluster are presented in Figure 8 supported by the data included in the Appendix. Graph A presents the calculated potential availability of agricultural waste and residue resources at 10 km intervals up to 100km from the central site, Graph B presents the calculated availability of industry residues.

- The research finds the scale of resources potentially available increases at a steady rate with distance away from the central site.
- There is larger resource and energy potentially sourced from animal wastes compared to crop residues. Wastes from cattle represents a leading resource opportunity available within each 10 km and gradually increasing, with over 1.5 Mt potentially available within 100 km of the site. Sheep manure may provide over 1.2 Mt within 100 km of the site, particularly available between the 50-100km radius. Chicken litter and pig manure may provide over 90 and 80 thousand tonnes respectively within 100 km of site, although are most abundance within the 60-100km radius zone.
- The leading crop residues are wastes from potato production and processing and straw from wheat, potentially providing over 160 and 125 thousand tonnes respectively within a 100 km radius of the site. Although there are limited crop residues potentially available within the initial 30km radius zone.
- Residues from forest industry activities may provide over 1.2 Mt of resource within 100km of the site. Although significant resource quantities are shown to be limited within the initial 30km radius zone.
- Collectively MSW and industry wastes that would otherwise be sent to landfill represent a major resource opportunity at each radius zone from the site. Leading waste streams include food that may provide over 300 thousand tonnes within 100km and wood, card, paper from both households and industry that may collectively provide over 1 Mt within the 100km radius.

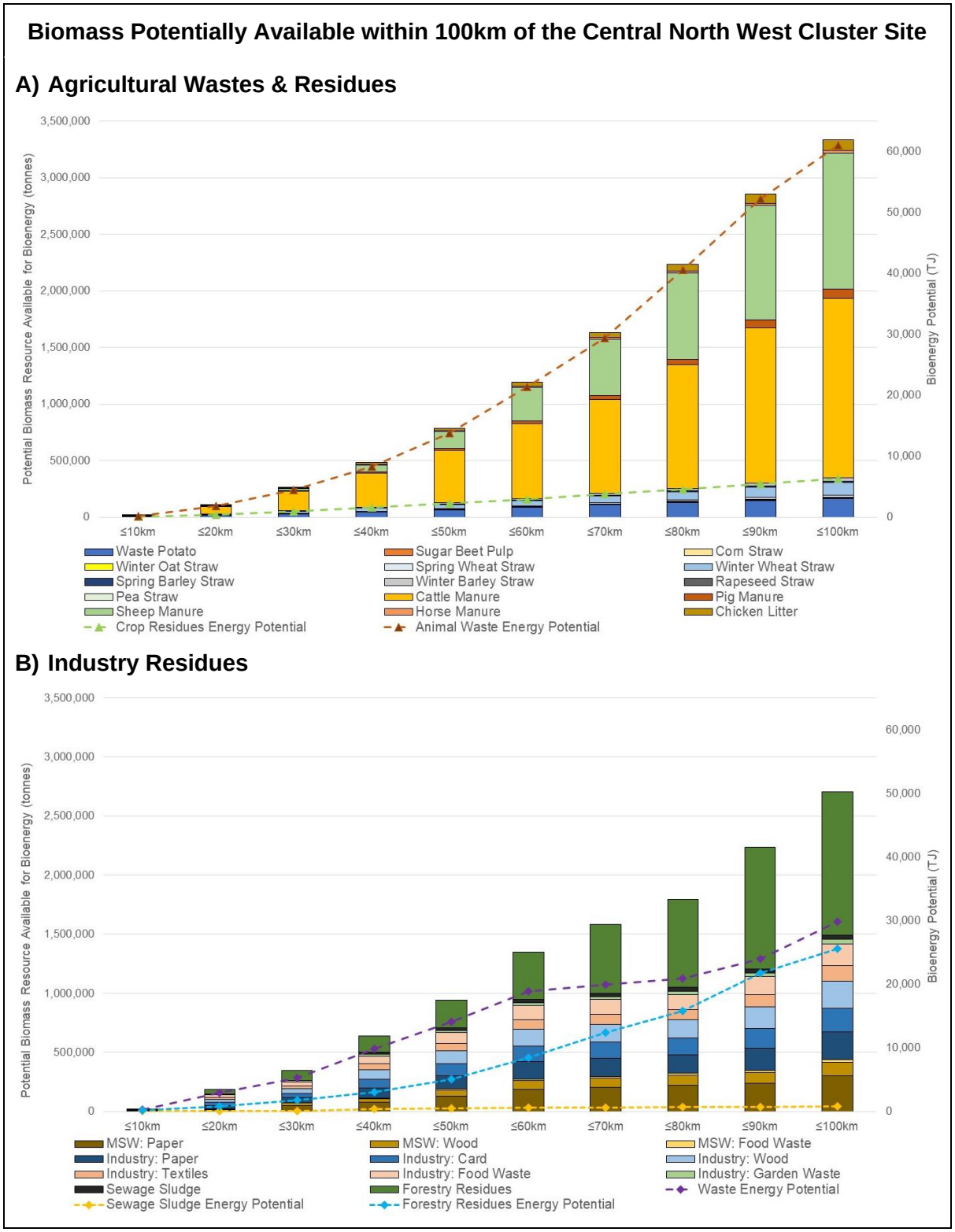

Figure 8: Biomass Resource & Bioenergy Potential Estimates for the North West Cluster Centralised Biofuel Production Site. Cumulative biomass resource potential estimates (tonnes) at ≤10km radii up to 100km from the centralised biofuel production site. Bioenergy potential estimates (TJ), indicating the total energy potentially generated given feedstock availability (tonnes) and calorific values (MJ/Kg, Section 2.2).

4.3. Humber Cluster - Biomass Resource Availability

The results of the resource modelling for the Humber cluster are presented in Figure 9 supported by the data included in the Appendix. Graph A presents the calculated potential available agricultural waste and residue resources at 10 km intervals up to 100km from the central site, Graph B presents the calculated availability of industry residues.

- The research finds there are limited resource opportunities within the near vicinity of the central Humber site (up to 20km) although the available resource rapidly increases with distance particularly beyond 40km.
- There are a broad range of animal wastes that may provide opportunities for the bioenergy sector. Within each radius zone waste from cattle represent the largest resource opportunity, providing up to 1 Mt within 100km of the site. Beyond the 40km radius there are also clear potential opportunities from sheep and pig manure and chicken litter, providing over 650, 350 and 140 thousand tonnes respectively within 100km of the site.
- The leading crop residue biomass are wastes from potato production and processing and straw from wheat, potentially providing over 340 and 430 thousand tonnes respectively within a 100 km radius of the site. There is also potential barley straw available beyond the 60km radius zone, providing over 140 thousand tonnes within a 100 km radius of the site.
- MSW and industry wastes are shown to represent a potentially significant resource opportunity for the bioenergy sector. Food waste are shown to be available particularly beyond the 40km radius zone, potentially providing over 240 thousand tonnes within a 100 km radius of the site. Wood, card, paper from both households and industry that may collectively provide over 1.2 Mt within a 100km radius from the site, and are shown to provide a potentially consistent resource across each radius zone.
- Residues from forest industry activities are less abundant in the Humber region although may still provide over 900 thousand tonnes within 100km of the site, particularly beyond the 40km radius zone.

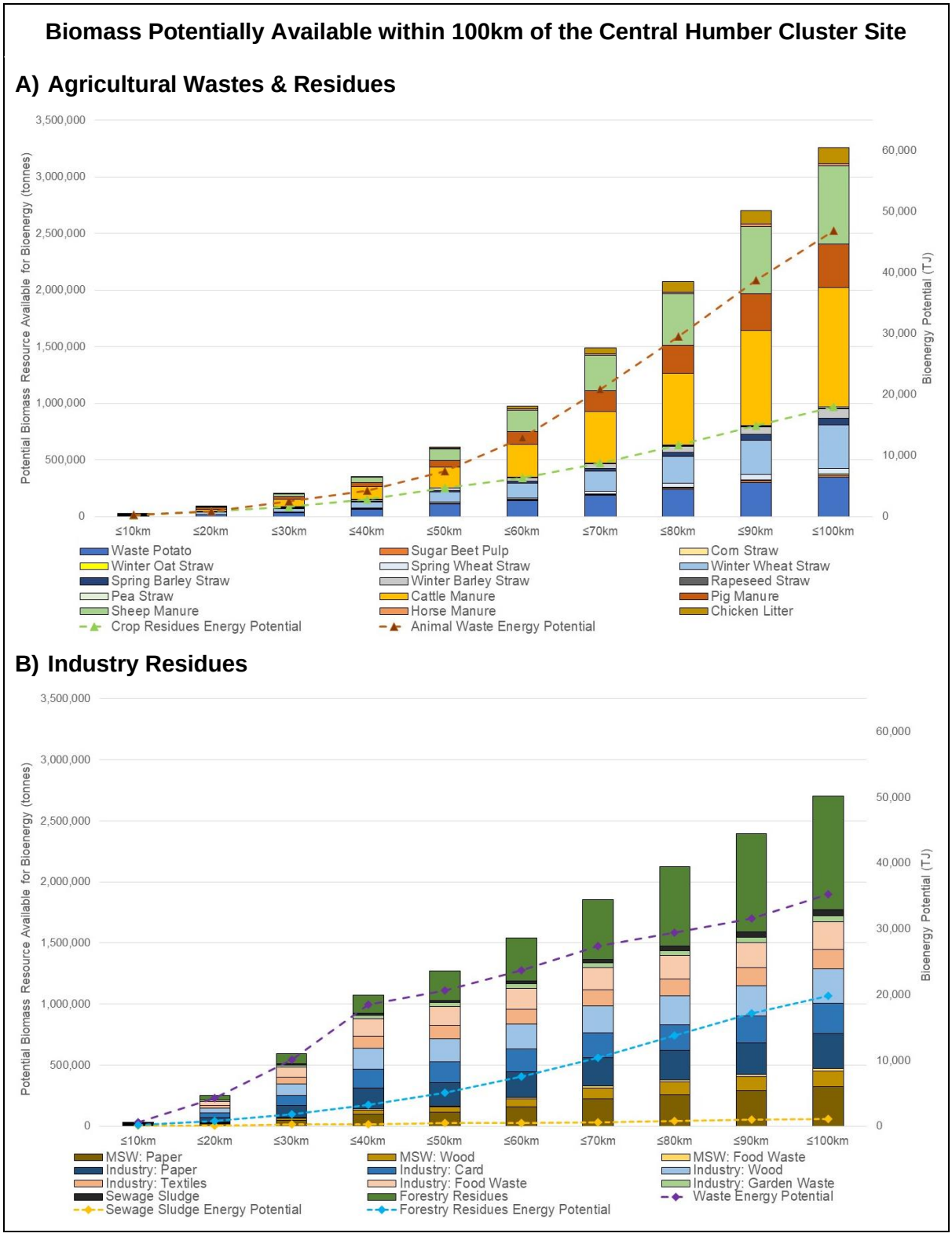

Figure 9: Biomass Resource & Bioenergy Potential Estimates for the Humber Cluster Centralised Biofuel Production Site. Cumulative biomass resource potential estimates (tonnes) at ≤10km radii upto 100km from the centralised biofuel production site. Bioenergy potential estimates (TJ), indicating the total energy potentially generated given feedstock availability (tonnes) and calorific values (MJ/Kg, Section 2.2).

5. Conclusions

The glass sector has high energy demands driven by the fuel requirements to continually operate glass furnaces. This research analyses the feasibility of using UK waste and residue biomass resources to provide alternative low carbon fuels for the sector. Biomass resource modelling calculations were completed to identify the leading resource opportunities within the regions where the UK's glass manufacturing sites are concentrated. The research focused on three case study sites: i) the large OI Glass facility in Scotland; ii) the glass manufacturing cluster in the North West region of England, and; iii) the glass manufacturing cluster in Humber region of North East England. The research found:

- At each Case Study sites analysed large quantities of biomass have been identified within a 50/100km radius of the site. The characteristics of biomass resource potentially available across the different regions of the UK varies. There are consistent potential opportunities from agriculture and industry activities. The specific categories of biomass and their availability depends on the spatial distribution of such activities and their focus.
- Based on the available resource and comparative energy demands of key manufacturing sites, the optimal location for a centralised biofuel production facility serving the glass sector in the North West of England is potentially near Helsby in Cheshire. The optimal location for a centralised facility serving the glass sector in the Humber region is potentially near Shafton in South Yorkshire.
- Animal wastes represent significant resource opportunity in each region analysed, particularly cattle manure. There are limited existing uses for this resource and ideally manure would be processed and converted to advanced fuels within close proximity of its source.
- Agricultural crop residues are a further leading resource opportunity available across the UK. By-product materials such as wastes from potato production/ processing and straws from core cereal crops such as wheat and barley are found to be consistently available in the regions where UK glass manufacturing is concentrated. There are existing uses for many crop residues particularly for wider agricultural activities, although research shows sustainable levels may be mobilised for bioenergy without adversely impacts existing activities.
- Residues from forestry sector activities such as mills are identified as a consistent biomass opportunity across each of the regions analysed, particularly Scotland and the North West of England. Large quantities of residue material are generated in the production of wood products. These residues are already partly used by the bioenergy sector to produce pellet fuels etc.
- Waste materials that would otherwise be sent to landfill are found to be a potentially significant resource opportunity for the bioenergy sector where they can be mobilised. UK households and industry generate large quantities of wastes the are managed through the waste hierarchy. Greater use of wood, paper, card and food materials that are currently sent to landfill could generate significant quantities of energy/ fuels and mitigate significant environmental impacts.

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Appendix

A. OI Glass Site – Biomass Resource Availability

Total Biomass (within each spatial zone)

OI Facility Biomass (tonnes)	Singular Zones				
Agricultural Residues	*10km*	*20km*	*30km*	*40km*	*50km*
Waste Potato	0	1,411	5,374	39,353	37,796
Sugar Beet Pulp	0	0	0	0	0
Corn Straw	0	0	0	0	0
Winter Oat Straw	424	571	430	816	1,639
Spring Wheat Straw	438	2,029	2,330	4,043	4,918
Winter Wheat Straw	2,184	8,291	7,762	17,654	22,159
Spring Barley Straw	2,277	11,322	13,144	23,512	26,693
Winter Barley Straw	567	2,275	3,351	7,340	6,937
Rapeseed Straw	50	173	513	1,231	1,534
Pea Straw	0	0	64	1,834	2,391
Cattle Manure	4,759	32,490	58,711	104,206	83,943
Pig Manure	5	259	193	10,012	1,726
Sheep Manure	6,673	48,623	99,470	145,068	83,909
Horse Manure	0	10,902	3,159	3,201	2,573
Chicken Litter	6,601	6,144	13,036	23,474	47,120

Industrial Wastes	*10km*	*20km*	*30km*	*40km*	*50km*
MSW: Paper	7,725	15,217	29,400	37,371	79,830
MSW: Wood	1,900	3,742	7,230	9,189	19,630
MSW: Food Waste	437	860	1,662	2,112	4,512
Industry: Paper	0	2,337	16,491	10,013	28,454
Industry: Card	0	2,065	14,570	8,846	25,139
Industry: Wood	0	2,269	16,011	9,721	27,625
Industry: Textiles	0	1,339	9,446	5,735	16,299
Industry: Food Waste	0	1,861	13,129	7,971	22,653
Industry: Garden Waste	0	408	2,882	1,750	4,973
Sewage Sludge	362	1,230	1,072	1,078	1,785
Forestry Residues	21,006	212,598	505,030	621,197	494,268

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Total Biomass (cumulative across zones)

OI Facility Biomass (tonnes)	Cumulative Zones				
Crop Residues	*≤10km*	*≤20km*	*≤30km*	*≤40km*	*≤50km*
Waste Potato	0	1,411	6,785	46,138	83,934
Sugar Beet Pulp	0	0	0	0	0
Corn Straw	0	0	0	0	0
Winter Oat Straw	424	996	1,425	2,241	3,880
Spring Wheat Straw	438	2,467	4,797	8,839	13,757
Winter Wheat Straw	2,184	10,476	18,237	35,892	58,051
Spring Barley Straw	2,277	13,599	26,743	50,255	76,948
Winter Barley Straw	567	2,843	6,193	13,533	20,471
Rapeseed Straw	50	223	736	1,967	3,501
Pea Straw	0	0	64	1,899	4,290
Cattle Manure	4,759	37,250	95,961	200,166	284,110
Pig Manure	5	264	457	10,469	12,195
Sheep Manure	6,673	55,296	154,766	299,834	383,744
Horse Manure	0	10,902	14,062	17,263	19,836
Poultry Litter	6,601	12,745	25,781	49,254	96,374

Industrial Wastes	*≤10km*	*≤20km*	*≤30km*	*≤40km*	*≤50km*
MSW: Paper	7,725	22,943	52,343	89,713	169,544
MSW: Wood	1,900	5,642	12,871	22,060	41,690
MSW: Food Waste	437	1,297	2,958	5,070	9,582
Industry: Paper	0	2,337	18,828	28,841	57,295
Industry: Card	0	2,065	16,635	25,481	50,620
Industry: Wood	0	2,269	18,280	28,001	55,626
Industry: Textiles	0	1,339	10,785	16,520	32,819
Industry: Food Waste	0	1,861	14,989	22,961	45,613
Industry: Garden Waste	0	408	3,290	5,040	10,013
Sewage Sludge	362	1,592	2,665	3,742	5,527
Forestry Residues	21,006	233,603	738,633	1,359,830	1,854,098

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Potential Biomass Availability for the Glass Sector (within each spatial zone)

OI Facility Biomass (tonnes)	Singular Zones					
Agricultural Residues	*10km*	*20km*	*30km*	*40km*	*50km*	*Availability Assumption*
Waste Potato	0	501	1,908	13,970	13,417	0.36
Sugar Beet Pulp	0	0	0	0	0	0.18
Corn Straw	0	0	0	0	0	0.09
Winter Oat Straw	119	160	120	228	459	0.28
Spring Wheat Straw	123	568	652	1,132	1,377	0.28
Winter Wheat Straw	612	2,322	2,173	4,943	6,205	0.28
Spring Barley Straw	638	3,170	3,680	6,583	7,474	0.28
Winter Barley Straw	159	637	938	2,055	1,942	0.28
Rapeseed Straw	5	16	47	114	142	0.09
Pea Straw	0	0	6	170	221	0.09
Cattle Manure	2,522	17,220	31,117	55,229	44,490	0.53
Pig Manure	1	49	37	1,902	328	0.19
Sheep Manure	2,229	16,240	33,223	48,453	28,026	0.33
Horse Manure	0	3,162	916	928	746	0.29
Chicken Litter	1,848	1,720	3,650	6,573	13,194	0.28

Industrial Wastes	*10km*	*20km*	*30km*	*40km*	*50km*	*Availability Assumption*
MSW: Paper	2,657	5,235	10,114	12,855	27,462	0.34
MSW: Wood	1,062	2,092	4,041	5,137	10,973	0.56
MSW: Food Waste	186	367	708	900	1,923	0.43
Industry: Paper	0	2,337	16,491	10,013	28,454	1.00
Industry: Card	0	2,065	14,570	8,846	25,139	1.00
Industry: Wood	0	2,269	16,011	9,721	27,625	1.00
Industry: Textiles	0	1,339	9,446	5,735	16,299	1.00
Industry: Food Waste	0	1,861	13,129	7,971	22,653	1.00
Industry: Garden Waste	0	408	2,882	1,750	4,973	1.00
Sewage Sludge	210	713	622	625	1,035	0.58
Forestry Residues	10,923	110,551	262,616	323,022	257,019	0.52

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Potential Biomass Availability for the Glass Sector (cumulative across zones)

OI Facility Biomass (tonnes)	Cumulative Zones					
Agricultural Residues	*≤10km*	*≤20km*	*≤30km*	*≤40km*	*≤50km*	*Availability Assumption*
Waste Potato	0	501	2,409	16,379	29,796	0.36
Sugar Beet Pulp	0	0	0	0	0	0.18
Corn Straw	0	0	0	0	0	0.09
Winter Oat Straw	119	279	399	628	1,086	0.28
Spring Wheat Straw	123	691	1,343	2,475	3,852	0.28
Winter Wheat Straw	612	2,933	5,106	10,050	16,254	0.28
Spring Barley Straw	638	3,808	7,488	14,071	21,545	0.28
Winter Barley Straw	159	796	1,734	3,789	5,732	0.28
Rapeseed Straw	5	21	68	182	324	0.09
Pea Straw	0	0	6	176	397	0.09
Cattle Manure	2,522	19,742	50,859	106,088	150,578	0.53
Pig Manure	1	50	87	1,989	2,317	0.19
Sheep Manure	2,229	18,469	51,692	100,145	128,170	0.33
Horse Manure	0	3,162	4,078	5,006	5,752	0.29
Chicken Litter	1,848	3,569	7,219	13,791	26,985	0.28

Industrial Wastes	*≤10km*	*≤20km*	*≤30km*	*≤40km*	*≤50km*	*Availability Assumption*
MSW: Paper	2,657	7,892	18,006	30,861	58,323	0.34
MSW: Wood	1,062	3,154	7,195	12,332	23,305	0.56
MSW: Food Waste	186	553	1,261	2,161	4,084	0.43
Industry: Paper	0	2,337	18,828	28,841	57,295	1.00
Industry: Card	0	2,065	16,635	25,481	50,620	1.00
Industry: Wood	0	2,269	18,280	28,001	55,626	1.00
Industry: Textiles	0	1,339	10,785	16,520	32,819	1.00
Industry: Food Waste	0	1,861	14,989	22,961	45,613	1.00
Industry: Garden Waste	0	408	3,290	5,040	10,013	1.00
Sewage Sludge	210	923	1,545	2,171	3,206	0.58
Forestry Residues	10,923	121,474	384,089	707,112	964,131	0.52

B. North West Glass Industry Cluster – Biomass Resource Availability

Total Biomass (within each spatial zone)

NW Cluster Biomass (tonnes)	Singular Zones									
Agricultural Residues	*10km*	*20km*	*30km*	*40km*	*50km*	*60km*	*70km*	*80km*	*90km*	*100km*
Waste Potato	8,078	31,476	41,198	48,112	54,407	55,339	67,562	60,820	48,613	47,199
Sugar Beet Pulp	0	0	0	0	0	0	0	0	0	0
Corn Straw	711	3,608	6,049	6,609	7,761	7,655	6,300	6,160	6,290	3,765
Winter Oat Straw	172	2,400	2,980	3,886	4,928	1,582	1,549	2,268	5,141	4,835
Spring Wheat Straw	369	1,858	3,958	5,547	10,372	9,893	7,627	4,866	6,299	4,556
Winter Wheat Straw	4,252	18,687	33,128	31,288	31,748	33,283	48,187	57,908	68,258	71,898
Spring Barley Straw	649	1,882	3,186	5,762	6,896	6,127	5,275	3,873	8,062	8,561
Winter Barley Straw	592	4,204	9,849	10,087	11,115	9,474	11,970	8,721	17,344	16,550
Rapeseed Straw	261	729	1,149	1,179	1,089	1,992	4,331	4,097	5,129	5,116
Pea Straw	163	336	41	0	120	1,106	1,253	837	338	474
Cattle Manure	13,373	115,096	195,769	245,429	304,676	370,309	321,724	489,316	529,513	399,278
Pig Manure	1,976	22,988	15,577	18,783	30,269	44,472	56,843	86,724	85,861	69,250
Sheep Manure	4,181	18,999	32,615	125,632	264,118	448,013	595,243	784,293	757,175	572,428
Horse Manure	323	3,085	6,088	9,369	10,654	12,623	9,756	10,103	10,740	11,959
Chicken Litter	1,984	7,889	21,851	20,912	21,154	41,202	43,062	56,816	64,020	44,468
Industrial Wastes	*10km*	*20km*	*30km*	*40km*	*50km*	*60km*	*70km*	*80km*	*90km*	*100km*
MSW: Paper	4,427	40,994	101,297	77,144	152,351	162,239	46,092	52,937	45,688	184,773
MSW: Wood	1,089	10,080	24,909	18,970	37,463	39,894	11,334	13,017	11,234	45,435
MSW: Food Waste	250	2,317	5,725	4,360	8,611	9,169	2,605	2,992	2,582	10,443
Industry: Paper	2,476	25,287	14,028	42,432	28,590	34,700	6,452	4,172	29,869	43,472
Industry: Card	2,188	22,341	12,394	37,489	25,259	30,657	5,701	3,686	26,389	38,407
Industry: Wood	2,404	24,550	13,620	41,196	27,757	33,689	6,264	4,050	28,999	42,205
Industry: Textiles	1,418	14,485	8,036	24,306	16,377	19,877	3,696	2,390	17,109	24,901
Industry: Food Waste	1,971	20,131	11,168	33,781	22,761	27,625	5,137	3,321	23,779	34,608
Industry: Garden Waste	433	4,419	2,452	7,415	4,996	6,064	1,128	729	5,220	7,597
Sewage Sludge	811	2,843	3,844	17,693	9,761	6,157	7,271	3,469	4,690	6,901
Forestry Residues	14,085	62,820	80,297	117,799	180,711	314,896	351,911	311,542	542,825	346,835

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Total Biomass (cumulative across zones)

NW Cluster Biomass (tonnes)	Cumulative Zones									
Crop Residues	*≤10km*	*≤20km*	*≤30km*	*≤40km*	*≤50km*	*≤60km*	*≤70km*	*≤80km*	*≤90km*	*≤100km*
Waste Potato	8,078	39,554	80,752	128,864	183,272	238,611	306,173	366,994	415,607	462,805
Sugar Beet Pulp	0	0	0	0	0	0	0	0	0	0
Corn Straw	711	4,319	10,368	16,977	24,738	32,393	38,694	44,854	51,144	54,909
Winter Oat Straw	172	2,571	5,551	9,437	14,366	15,947	17,497	19,765	24,906	29,741
Spring Wheat Straw	369	2,226	6,185	11,731	22,103	31,996	39,623	44,489	50,788	55,344
Winter Wheat Straw	4,252	22,939	56,066	87,354	119,102	152,385	200,572	258,480	326,738	398,636
Spring Barley Straw	649	2,531	5,718	11,479	18,375	24,502	29,777	33,650	41,712	50,273
Winter Barley Straw	592	4,796	14,645	24,732	35,847	45,320	57,290	66,012	83,356	99,906
Rapeseed Straw	261	990	2,138	3,317	4,406	6,398	10,729	14,826	19,955	25,071
Pea Straw	163	498	539	539	659	1,765	3,018	3,854	4,192	4,666
Cattle Manure	13,373	128,470	324,239	569,668	874,344	1,244,653	1,566,377	2,055,692	2,585,206	2,984,484
Pig Manure	1,976	24,964	40,542	59,325	89,594	134,066	190,909	277,633	363,494	432,744
Sheep Manure	4,181	23,180	55,795	181,427	445,546	893,558	1,488,801	2,273,094	3,030,270	3,602,697
Horse Manure	323	3,408	9,496	18,865	29,518	42,141	51,897	62,000	72,740	84,699
Poultry Litter	1,984	9,873	31,724	52,636	73,790	114,992	158,054	214,869	278,889	323,357
Industrial Wastes	*≤10km*	*≤20km*	*≤30km*	*≤40km*	*≤50km*	*≤60km*	*≤70km*	*≤80km*	*≤90km*	*≤100km*
MSW: Paper	4,427	45,421	146,718	223,862	376,214	538,453	584,545	637,482	683,170	867,942
MSW: Wood	1,089	11,169	36,078	55,047	92,510	132,404	143,738	156,755	167,990	213,425
MSW: Food Waste	250	2,567	8,292	12,652	21,263	30,432	33,037	36,029	38,611	49,054
Industry: Paper	2,476	27,763	41,791	84,224	112,813	147,513	153,966	158,138	188,006	231,478
Industry: Card	2,188	24,528	36,922	74,411	99,670	130,327	136,028	139,714	166,103	204,510
Industry: Wood	2,404	26,954	40,574	81,771	109,528	143,217	149,481	153,532	182,530	224,736
Industry: Textiles	1,418	15,903	23,939	48,245	64,621	84,498	88,194	90,584	107,693	132,594
Industry: Food Waste	1,971	22,103	33,271	67,052	89,813	117,438	122,575	125,896	149,675	184,283
Industry: Garden Waste	433	4,852	7,303	14,719	19,715	25,779	26,907	27,636	32,855	40,452
Sewage Sludge	811	3,655	7,498	25,191	34,952	41,109	48,380	51,849	56,540	63,441
Forestry Residues	14,085	76,905	157,202	275,001	455,712	770,608	1,122,519	1,434,061	1,976,886	2,323,722

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Potential Biomass Availability for the Glass Sector (within each spatial zone)

NW Cluster Biomass (tonnes)	Singular Zones										
Agricultural Residues	*10km*	*20km*	*30km*	*40km*	*50km*	*60km*	*70km*	*80km*	*90km*	*100km*	*Availability Assumption*
Waste Potato	2,868	11,174	14,625	17,080	19,315	19,645	23,985	21,591	17,258	16,756	0.36
Sugar Beet Pulp	0	0	0	0	0	0	0	0	0	0	0.18
Corn Straw	64	325	544	595	698	689	567	554	566	339	0.09
Winter Oat Straw	48	672	834	1,088	1,380	443	434	635	1,440	1,354	0.28
Spring Wheat Straw	103	520	1,108	1,553	2,904	2,770	2,136	1,362	1,764	1,276	0.28
Winter Wheat Straw	1,191	5,232	9,276	8,761	8,889	9,319	13,492	16,214	19,112	20,131	0.28
Spring Barley Straw	182	527	892	1,613	1,931	1,716	1,477	1,084	2,257	2,397	0.28
Winter Barley Straw	166	1,177	2,758	2,824	3,112	2,653	3,352	2,442	4,856	4,634	0.28
Rapeseed Straw	24	67	106	109	101	184	401	379	474	473	0.09
Pea Straw	15	31	4	0	11	102	116	77	31	44	0.09
Cattle Manure	7,088	61,001	103,758	130,078	161,478	196,264	170,514	259,337	280,642	211,618	0.53
Pig Manure	375	4,368	2,960	3,569	5,751	8,450	10,800	16,478	16,314	13,157	0.19
Sheep Manure	1,397	6,346	10,893	41,961	88,216	149,636	198,811	261,954	252,897	191,191	0.33
Horse Manure	94	895	1,765	2,717	3,090	3,661	2,829	2,930	3,114	3,468	0.29
Chicken Litter	556	2,209	6,118	5,855	5,923	11,536	12,057	15,908	17,926	12,451	0.28

Industrial Wastes	*10km*	*20km*	*30km*	*40km*	*50km*	*60km*	*70km*	*80km*	*90km*	*100km*	*Availability Assumption*
MSW: Paper	1,523	14,102	34,846	26,538	52,409	55,810	15,856	18,210	15,717	63,562	0.34
MSW: Wood	609	5,635	13,924	10,604	20,942	22,301	6,336	7,277	6,280	25,398	0.56
MSW: Food Waste	107	987	2,440	1,858	3,670	3,908	1,110	1,275	1,101	4,451	0.43
Industry: Paper	2,476	25,287	14,028	42,432	28,590	34,700	6,452	4,172	29,869	43,472	1.00
Industry: Card	2,188	22,341	12,394	37,489	25,259	30,657	5,701	3,686	26,389	38,407	1.00
Industry: Wood	2,404	24,550	13,620	41,196	27,757	33,689	6,264	4,050	28,999	42,205	1.00
Industry: Textiles	1,418	14,485	8,036	24,306	16,377	19,877	3,696	2,390	17,109	24,901	1.00
Industry: Food Waste	1,971	20,131	11,168	33,781	22,761	27,625	5,137	3,321	23,779	34,608	1.00
Industry: Garden Waste	433	4,419	2,452	7,415	4,996	6,064	1,128	729	5,220	7,597	1.00
Sewage Sludge	471	1,649	2,229	10,262	5,661	3,571	4,217	2,012	2,720	4,003	0.58
Forestry Residues	7,324	32,666	41,755	61,256	93,970	163,746	182,994	162,002	282,269	180,354	0.52

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Potential Biomass Availability for the Glass Sector (cumulative across zones)

NW Cluster Biomass (tonnes)	Cumulative Zones										
Agricultural Residues	*≤10km*	*≤20km*	*≤30km*	*≤40km*	*≤50km*	*≤60km*	*≤70km*	*≤80km*	*≤90km*	*≤100km*	*Availability Assumption*
Waste Potato	2,868	14,042	28,667	45,747	65,061	84,707	108,692	130,283	147,540	164,296	0.36
Sugar Beet Pulp	0	0	0	0	0	0	0	0	0	0	0.18
Corn Straw	64	389	933	1,528	2,226	2,915	3,482	4,037	4,603	4,942	0.09
Winter Oat Straw	48	720	1,554	2,642	4,022	4,465	4,899	5,534	6,974	8,328	0.28
Spring Wheat Straw	103	623	1,732	3,285	6,189	8,959	11,094	12,457	14,221	15,496	0.28
Winter Wheat Straw	1,191	6,423	15,699	24,459	33,348	42,668	56,160	72,374	91,487	111,618	0.28
Spring Barley Straw	182	709	1,601	3,214	5,145	6,861	8,338	9,422	11,679	14,077	0.28
Winter Barley Straw	166	1,343	4,100	6,925	10,037	12,690	16,041	18,483	23,340	27,974	0.28
Rapeseed Straw	24	92	198	307	408	592	992	1,371	1,846	2,319	0.09
Pea Straw	15	46	50	50	61	163	279	357	388	432	0.09
Cattle Manure	7,088	68,089	171,847	301,924	463,402	659,666	830,180	1,089,517	1,370,159	1,581,777	0.53
Pig Manure	375	4,743	7,703	11,272	17,023	25,472	36,273	52,750	69,064	82,221	0.19
Sheep Manure	1,397	7,742	18,636	60,597	148,812	298,448	497,260	759,214	1,012,110	1,203,301	0.33
Horse Manure	94	988	2,754	5,471	8,560	12,221	15,050	17,980	21,095	24,563	0.29
Chicken Litter	556	2,765	8,883	14,738	20,661	32,198	44,255	60,163	78,089	90,540	0.28

Industrial Wastes	*≤10km*	*≤20km*	*≤30km*	*≤40km*	*≤50km*	*≤60km*	*≤70km*	*≤80km*	*≤90km*	*≤100km*	*Availability Assumption*
MSW: Paper	1,523	15,625	50,471	77,009	129,418	185,228	201,083	219,294	235,010	298,572	0.34
MSW: Wood	609	6,243	20,167	30,771	51,713	74,014	80,350	87,626	93,906	119,305	0.56
MSW: Food Waste	107	1,094	3,534	5,392	9,062	12,970	14,080	15,356	16,456	20,907	0.43
Industry: Paper	2,476	27,763	41,791	84,224	112,813	147,513	153,966	158,138	188,006	231,478	1.00
Industry: Card	2,188	24,528	36,922	74,411	99,670	130,327	136,028	139,714	166,103	204,510	1.00
Industry: Wood	2,404	26,954	40,574	81,771	109,528	143,217	149,481	153,532	182,530	224,736	1.00
Industry: Textiles	1,418	15,903	23,939	48,245	64,621	84,498	88,194	90,584	107,693	132,594	1.00
Industry: Food Waste	1,971	22,103	33,271	67,052	89,813	117,438	122,575	125,896	149,675	184,283	1.00
Industry: Garden Waste	433	4,852	7,303	14,719	19,715	25,779	26,907	27,636	32,855	40,452	1.00
Sewage Sludge	471	2,120	4,349	14,611	20,272	23,843	28,061	30,073	32,793	36,796	0.58
Forestry Residues	7,324	39,990	81,745	143,001	236,970	400,716	583,710	745,712	1,027,981	1,208,335	0.52

C. Humber West Glass Industry Cluster – Biomass Resource Availability

Total Biomass (within each spatial zone)

Biomass (tonnes)	Singular Zones									
Agricultural Residues	*10km*	*20km*	*30km*	*40km*	*50km*	*60km*	*70km*	*80km*	*90km*	*100km*
Waste Potato	8,931	35,716	48,972	82,230	134,333	81,737	128,155	158,078	168,226	126,259
Sugar Beet Pulp	38	3,176	5,758	9,291	10,497	8,722	11,601	15,104	14,704	13,184
Corn Straw	97	672	1,578	2,984	5,027	4,341	7,005	7,127	8,722	7,868
Winter Oat Straw	424	1,073	658	1,583	2,769	2,256	2,307	4,142	9,483	6,725
Spring Wheat Straw	1,006	2,618	3,370	10,983	18,006	17,322	29,213	36,359	32,889	29,332
Winter Wheat Straw	19,018	47,388	54,635	76,647	118,016	140,066	172,938	216,139	246,862	264,562
Spring Barley Straw	1,053	4,561	8,229	12,618	18,620	21,077	35,411	37,724	37,740	49,136
Winter Barley Straw	5,614	11,178	10,779	18,658	25,420	28,246	36,014	44,140	51,312	55,756
Rapeseed Straw	978	2,350	3,513	5,468	7,679	9,755	14,969	17,123	19,574	19,183
Pea Straw	605	3,647	1,300	5,687	10,152	9,864	10,278	20,981	29,166	23,247
Cattle Manure	9,444	31,118	90,577	79,347	129,230	213,680	308,271	331,081	395,174	396,695
Pig Manure	31,153	48,231	42,144	76,155	127,325	260,238	355,436	364,269	382,174	350,938
Sheep Manure	1,321	11,377	47,387	75,108	166,543	272,392	366,859	423,288	419,419	276,006
Horse Manure	1,025	2,176	4,622	5,504	6,858	9,496	10,503	11,832	12,688	10,760
Chicken Litter	199	863	6,127	11,482	15,951	51,696	110,020	140,530	87,220	76,654

Industrial Wastes	*10km*	*20km*	*30km*	*40km*	*50km*	*60km*	*70km*	*80km*	*90km*	*100km*
MSW: Paper	5,339	51,430	78,862	138,403	49,014	135,942	191,220	98,790	87,905	98,595
MSW: Wood	1,313	12,647	19,392	34,033	12,052	33,428	47,020	24,292	21,616	24,244
MSW: Food Waste	302	2,907	4,457	7,822	2,770	7,683	10,807	5,583	4,968	5,572
Industry: Paper	5,299	36,209	55,953	77,676	17,575	19,241	17,877	11,106	14,325	29,246
Industry: Card	4,682	31,990	49,434	68,626	15,527	16,999	15,794	9,812	12,656	25,839
Industry: Wood	5,145	35,154	54,323	75,413	17,063	18,680	17,356	10,783	13,908	28,395
Industry: Textiles	3,036	20,741	32,051	44,494	10,067	11,021	10,240	6,362	8,206	16,753
Industry: Food Waste	4,219	28,826	44,545	61,839	13,992	15,318	14,232	8,842	11,404	23,284
Industry: Garden Waste	926	6,328	9,778	13,574	3,071	3,362	3,124	1,941	2,503	5,111
Sewage Sludge	791	3,277	15,753	3,515	8,582	5,467	6,131	17,074	12,850	8,613
Forestry Residues	12,837	57,641	93,740	128,971	166,957	224,065	263,319	301,247	307,209	239,700

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Total Biomass (cumulative across zones)

Biomass (tonnes)	Cumulative Zones									
Crop Residues	*≤10km*	*≤20km*	*≤30km*	*≤40km*	*≤50km*	*≤60km*	*≤70km*	*≤80km*	*≤90km*	*≤100km*
Waste Potato	8,931	44,647	93,619	175,849	310,181	391,919	520,074	678,152	846,378	972,638
Sugar Beet Pulp	38	3,214	8,972	18,263	28,761	37,483	49,084	64,189	78,893	92,077
Corn Straw	97	769	2,347	5,331	10,358	14,699	21,704	28,831	37,553	45,422
Winter Oat Straw	424	1,497	2,155	3,738	6,507	8,764	11,071	15,213	24,697	31,421
Spring Wheat Straw	1,006	3,624	6,994	17,977	35,983	53,305	82,517	118,876	151,766	181,097
Winter Wheat Straw	19,018	66,406	121,041	197,689	315,705	455,771	628,709	844,848	1,091,710	1,356,273
Spring Barley Straw	1,053	5,614	13,842	26,460	45,080	66,157	101,568	139,292	177,032	226,168
Winter Barley Straw	5,614	16,792	27,571	46,229	71,649	99,895	135,908	180,048	231,361	287,116
Rapeseed Straw	978	3,328	6,840	12,308	19,988	29,742	44,711	61,834	81,408	100,591
Pea Straw	605	4,252	5,553	11,239	21,391	31,255	41,533	62,514	91,680	114,926
Cattle Manure	9,444	40,562	131,139	210,487	339,716	553,396	861,667	1,192,749	1,587,922	1,984,618
Pig Manure	31,153	79,385	121,529	197,683	325,008	585,246	940,682	1,304,951	1,687,125	2,038,063
Sheep Manure	1,321	12,697	60,084	135,192	301,735	574,127	940,986	1,364,274	1,783,694	2,059,699
Horse Manure	1,025	3,201	7,823	13,327	20,185	29,681	40,184	52,016	64,704	75,464
Poultry Litter	199	1,062	7,190	18,671	34,623	86,319	196,339	336,869	424,090	500,744

Industrial Wastes	*≤10km*	*≤20km*	*≤30km*	*≤40km*	*≤50km*	*≤60km*	*≤70km*	*≤80km*	*≤90km*	*≤100km*
MSW: Paper	5,339	56,770	135,632	274,035	323,050	458,992	650,211	749,001	836,906	935,501
MSW: Wood	1,313	13,960	33,352	67,385	79,437	112,865	159,886	184,178	205,793	230,038
MSW: Food Waste	302	3,208	7,666	15,488	18,258	25,941	36,748	42,332	47,300	52,872
Industry: Paper	5,299	41,508	97,461	175,136	192,711	211,952	229,828	240,935	255,260	284,506
Industry: Card	4,682	36,672	86,106	154,732	170,259	187,258	203,052	212,865	225,521	251,360
Industry: Wood	5,145	40,299	94,622	170,035	187,098	205,779	223,134	233,917	247,825	276,219
Industry: Textiles	3,036	23,777	55,827	100,321	110,388	121,409	131,649	138,011	146,217	162,969
Industry: Food Waste	4,219	33,045	77,590	139,429	153,421	168,738	182,970	191,812	203,216	226,500
Industry: Garden Waste	926	7,254	17,032	30,606	33,678	37,040	40,164	42,105	44,608	49,719
Sewage Sludge	791	4,067	19,821	23,336	31,918	37,386	43,516	60,590	73,440	82,053
Forestry Residues	12,837	70,478	164,218	293,190	460,147	684,212	947,532	1,248,778	1,555,988	1,795,688

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Potential Biomass Availability for the Glass Sector (within each spatial zone)

Humber Cluster Biomass (tonnes)	Singular Zones										
Agricultural Residues	*10km*	*20km*	*30km*	*40km*	*50km*	*60km*	*70km*	*80km*	*90km*	*100km*	*Availability Assumption*
Waste Potato	3,170	12,679	17,385	29,192	47,688	29,017	45,495	56,118	59,720	44,822	0.36
Sugar Beet Pulp	7	572	1,036	1,672	1,889	1,570	2,088	2,719	2,647	2,373	0.18
Corn Straw	9	60	142	269	452	391	630	641	785	708	0.09
Winter Oat Straw	119	300	184	443	775	632	646	1,160	2,655	1,883	0.28
Spring Wheat Straw	282	733	943	3,075	5,042	4,850	8,180	10,181	9,209	8,213	0.28
Winter Wheat Straw	5,325	13,269	15,298	21,461	33,045	39,219	48,423	60,519	69,121	74,077	0.28
Spring Barley Straw	295	1,277	#REF!	3,533	5,214	5,901	9,915	10,563	10,567	13,758	0.28
Winter Barley Straw	1,572	3,130	2,304	5,224	7,118	7,909	10,084	12,359	14,367	15,612	0.28
Rapeseed Straw	90	217	325	506	710	902	1,385	1,584	1,811	1,774	0.09
Pea Straw	56	337	120	526	939	912	951	1,941	2,698	2,150	0.09
Cattle Manure	5,005	16,493	48,006	42,054	68,492	113,250	163,384	175,473	209,442	210,249	0.53
Pig Manure	5,919	9,164	8,007	14,469	24,192	49,445	67,533	69,211	72,613	66,678	0.19
Sheep Manure	441	3,800	15,827	25,086	55,625	90,979	122,531	141,378	140,086	92,186	0.33
Horse Manure	297	631	1,340	1,596	1,989	2,754	3,046	3,431	3,679	3,120	0.29
Chicken Litter	56	242	1,716	3,215	4,466	14,475	30,806	39,348	24,422	21,463	0.28

Industrial Wastes	*10km*	*20km*	*30km*	*40km*	*50km*	*60km*	*70km*	*80km*	*90km*	*100km*	*Availability Assumption*
MSW: Paper	1,837	17,692	27,129	47,611	16,861	46,764	65,780	33,984	30,239	33,917	0.34
MSW: Wood	734	7,069	10,840	19,025	6,737	18,686	26,284	13,579	12,083	13,553	0.56
MSW: Food Waste	129	1,239	1,900	3,334	1,181	3,275	4,606	2,380	2,117	2,375	0.43
Industry: Paper	5,299	36,209	55,953	77,676	17,575	19,241	17,877	11,106	14,325	29,246	1.00
Industry: Card	4,682	31,990	49,434	68,626	15,527	16,999	15,794	9,812	12,656	25,839	1.00
Industry: Wood	5,145	35,154	54,323	75,413	17,063	18,680	17,356	10,783	13,908	28,395	1.00
Industry: Textiles	3,036	20,741	32,051	44,494	10,067	11,021	10,240	6,362	8,206	16,753	1.00
Industry: Food Waste	4,219	28,826	44,545	61,839	13,992	15,318	14,232	8,842	11,404	23,284	1.00
Industry: Garden Waste	926	6,328	9,778	13,574	3,071	3,362	3,124	1,941	2,503	5,111	1.00
Sewage Sludge	459	1,900	9,137	2,039	4,978	3,171	3,556	9,903	7,453	4,995	0.58
Forestry Residues	6,675	29,974	48,745	67,065	86,818	116,514	136,926	156,648	159,749	124,644	0.52

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Potential Biomass Availability for the Glass Sector (cumulative across zones)

Biomass (tonnes)	Cumulative Zones										
Agricultural Residues	*10km*	*20km*	*30km*	*40km*	*50km*	*60km*	*70km*	*80km*	*90km*	*100km*	*Availability Assumption*
Waste Potato	3,170	15,850	33,235	62,426	110,114	139,131	184,626	240,744	300,464	345,286	0.36
Sugar Beet Pulp	7	579	1,615	3,287	5,177	6,747	8,835	11,554	14,201	16,574	0.18
Corn Straw	9	69	211	480	932	1,323	1,953	2,595	3,380	4,088	0.09
Winter Oat Straw	119	419	603	1,047	1,822	2,454	3,100	4,260	6,915	8,798	0.28
Spring Wheat Straw	282	1,015	1,958	5,034	10,075	14,925	23,105	33,285	42,494	50,707	0.28
Winter Wheat Straw	5,325	18,594	33,892	55,353	88,397	127,616	176,039	236,558	305,679	379,756	0.28
Spring Barley Straw	295	1,572	3,876	7,409	12,623	18,524	28,439	39,002	49,569	63,327	0.28
Winter Barley Straw	1,572	4,702	7,720	12,944	20,062	27,970	38,054	50,414	64,781	80,393	0.28
Rapeseed Straw	90	308	633	1,139	1,849	2,751	4,136	5,720	7,530	9,305	0.09
Pea Straw	56	393	514	1,040	1,979	2,891	3,842	5,782	8,480	10,631	0.09
Cattle Manure	5,005	21,498	69,504	111,558	180,050	293,300	456,684	632,157	841,599	1,051,847	0.53
Pig Manure	5,919	15,083	23,090	37,560	61,751	111,197	178,730	247,941	320,554	387,232	0.19
Sheep Manure	441	4,241	20,068	45,154	100,780	191,759	314,289	455,668	595,754	687,939	0.33
Horse Manure	297	928	2,269	3,865	5,854	8,608	11,653	15,085	18,764	21,885	0.29
Chicken Litter	56	297	2,013	5,228	9,694	24,169	54,975	94,323	118,745	140,208	0.28

Industrial Wastes	*10km*	*20km*	*30km*	*40km*	*50km*	*60km*	*70km*	*80km*	*90km*	*100km*	*Availability Assumption*
MSW: Paper	1,837	19,529	46,657	94,268	111,129	157,893	223,673	257,656	287,896	321,812	0.34
MSW: Wood	734	7,803	18,644	37,668	44,405	63,092	89,376	102,955	115,038	128,591	0.56
MSW: Food Waste	129	1,367	3,267	6,601	7,782	11,056	15,662	18,042	20,159	22,534	0.43
Industry: Paper	5,299	41,508	97,461	175,136	192,711	211,952	229,828	240,935	255,260	284,506	1.00
Industry: Card	4,682	36,672	86,106	154,732	170,259	187,258	203,052	212,865	225,521	251,360	1.00
Industry: Wood	5,145	40,299	94,622	170,035	187,098	205,779	223,134	233,917	247,825	276,219	1.00
Industry: Textiles	3,036	23,777	55,827	100,321	110,388	121,409	131,649	138,011	146,217	162,969	1.00
Industry: Food Waste	4,219	33,045	77,590	139,429	153,421	168,738	182,970	191,812	203,216	226,500	1.00
Industry: Garden Waste	926	7,254	17,032	30,606	33,678	37,040	40,164	42,105	44,608	49,719	1.00
Sewage Sludge	459	2,359	11,496	13,535	18,513	21,684	25,239	35,142	42,595	47,591	0.58
Forestry Residues	6,675	36,649	85,394	152,459	239,276	355,790	492,716	649,365	809,114	933,758	0.52

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