Greenprint for a Sustainable Future

Cambridge Light Rail

30 March 2019 (v8.0)

cambridge connect

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Contents

Preface

Cambridge is at a pivotal moment in its history

Cambridge is witnessing phenomenal and unprecedented economic expansion and population growth. Between 2011 – 2031 the population of the Cambridge region is expected to increase by ~120,000 people, the equivalent of the population of Cambridge city again over a period of 20 years. As a result, Cambridge is facing some of its greatest challenges. There are pressing needs for more housing and effective transport links. Safeguards for the unique and outstanding heritage, environment and quality of life in Cambridge from these pressures have never been more needed. Given the scale of this challenge, it is vital that solutions developed today are fit for purpose when they are operational. Short-term projects – much as they are needed – should not compromise, or close off, options that we can reasonably foresee to be needed in the future.

Step-change needed

Barriers to connectivity detract from our quality of life, stifle opportunities, impede economic growth, harm the environment, and cause unnecessary waste. These barriers will increase without major commitments to, and investment in, solutions that are right for the scale of the problem. Piece-meal, local solutions will at best fail to meet needs, and at worst cause irreparable damage. A step-change in thinking is needed to meet the unprecedented scale of the challenge Cambridge is facing.

Light rail benefits

Light Rail is a practical and important potential solution to Cambridge transport challenges, and is adopted in hundreds of cities world-wide. While more expensive in the near term, it should be considered seriously as part of integrated and enduring solutions. Light Rail offers the speed, capacity, frequency, reliability, convenience and accessibility to bring about the major improvements needed in the connectivity and efficiency of the Cambridge transport network. Light Rail is also highly scalable, to take account of growing future demand. It is the proven technology most likely to enable the substantial change in people's journey decisions that is needed to create a more sustainable city.

Far-sighted approach

The Cambridgeshire-Peterborough Combined Authority has responsibility for strategic planning of transport in the region, and is showing a far-sighted and progressive approach, including in its support for development of a mass transit solution for the region. Previously, such proposals were not being considered because they were viewed as undeliverable within funding and time constraints of the allocated 'City Deal' funding. We are encouraged since 2017 the Greater Cambridge Partnership (which took over responsibility for delivery of the City Deal) has shown a longer-term approach. Both organisations commissioned a high level appraisal of strategic mass transit options, including light rail in 2017. The principal conclusions of the initial report (Steer Davies Gleave 2018) were that a mass transit solution is needed, and that a network model very similar to that proposed by Cambridge Connect should be adopted, including with tunnels in the city centre. This was reaffirmed in the Strategic Outline Business Case for the Cambridgeshire Autonomous Metro (CAM), published in March 2019 (Steer 2019). Cambridge Connect strongly supports this more far-sighted approach for an integrated and sustainable transport strategy for the Cambridge region, although we would like to see more and stronger evidence in support of the rubber-tyred articulated bus that is proposed as the mode to operate on the CAM.

Cambridge Light Rail

Cambridge Connect has developed conceptual plans for a Cambridge Light Rail system. The first priority in the network we call the 'Isaac Newton Line', referencing the history of innovative approaches that are a hallmark of Cambridge. We envisage the network would be developed in a phased manner, with delivery of the core components by 2025, and additional phases being developed through to 2030. Much detailed technical work remains to be done, although Cambridge Connect believes that the evidence currently shows this approach would be an enduring and sustainable solution fit for purpose for Cambridge in the 21st Century.

Affordable and deliverable

The scale of investment needed is challenging, of that there is no doubt. By phasing delivery we suggest that this can be both affordable and practical. By selecting light rail as the mode of choice – a well-established and proven technology that is reliably deliverable and yet continually enhanced by new innovations – authorities can rely on a proven solution that will minimise exposure to risk.

In the first instance, the Isaac Newton Line (Phases 1A & 1B) would cost in the order of £957 m to deliver (£1.3 bn with 40% Optimism Bias), and this would meet many of the core needs in Cambridge city. Extending 22 km from the Girton Interchange to Granta Park, with a short tunnel in the city centre, the Isaac Newton Line would link together all of the campuses of the University of Cambridge, link the central city to the Addenbrookes Hospital area, integrate with major employment and technology clusters, and link closely with the regional and national heavy rail network. Phase 1A (overground, ~14 km) could be delivered for ~£407 m (£569 m with 40% Optimism Bias) by 2022.

Over the 12-year strategic delivery period for Cambridge Light Rail – which would see delivery in seven phases to include light rail lines to Cambourne and St Neots, Haverhill, Waterbeach and connect Eddington to the Science Park – the overall cost for the scheme would be £2.73 bn (£3.8 bn including a 40% Optimism Bias). This equates to an annual investment of £227 m annually (£316 m including 40% Optimism Bias) over the twelve-year strategic delivery period.

Greenprint for a Sustainable Future

Delivery of a very high quality light rail scheme that would meet the needs of economic development, protect the important heritage and landscape values of Cambridge, enhance our quality of life and social connectivity, drive modal shift, and support a more sustainable approach to transport in the region. This should be considered a very wise investment.

This approach would be transformational and highly positive for the region. It would support economic growth and the much-needed housing delivery, meet both business and University needs, would be highly valued by both current and future generations, and we think represents a 'Greenprint for a Sustainable Future'.

Authorship

This report has been prepared by Dr Colin Harris (Director, Cambridge Connect), Ian Brown (Vice President Railfuture and Board Member UK Tram), Peter Cushing (Former Director of Manchester Metrolink), Peter Wakefield (Vice Chair, Railfuture East Anglia), and Paul Hollinghurst (Regional Secretary, Railfuture East Anglia).

In addition, specialist inputs were commissioned for Section 5.4 on Urban Realm (Luca Leone, Director, Cambridge Architectural Research) and Section 6.2 on Archaeological Constraints (Christopher Evans, Head of the Cambridge Archaeological Unit, University of Cambridge).

We thank the wide range of individuals who have contributed through numerous discussions and ideas although who are not specifically authors of this report. Further details on author backgrounds are provided in Appendix One.

1 Cambridge Light Rail: Executive summary

Cambridge Connect was initiated to promote a strategic and sustainable approach to public transport in Cambridge over the long-term. Emphasis is placed on light rail as part of that strategy, and on an integrated and multi-modal approach to meeting the transport needs for Cambridge and the surrounding region.

A light rail route we call the 'Isaac Newton Line' has been identified as a 'backbone' to meet priority Cambridge public transport needs, extending from the Girton Interchange in the northwest to Granta Park in the southeast over a distance of ~22 km (~14 mi) (Figure 1).

The light rail network serving city and regional needs would be developed in phases with a long-term vision as indicated in Table 1 and Figures 1 (City Network) and 2 (Regional Network). The light rail network has been designed so that it closely couples with the principal stations on the heavy rail network, providing excellent regional and national integration.

Table 1. Cambridge Light Rail overall vision and phasing.

Phase	Timing	Route	Features
1A	2018-22	'Isaac Newton Line'. Cambridge Central Rail station > Trumpington (M11) > Addenbrookes > Sawston > Granta Park.	Overground. Convert southern Cambridge Guided Busway (CGB). Supports Biomedical Campus and Biotech Cluster.
1B	2018-24	'Isaac Newton Line'. Cambridge Central Rail station > City Centre > West Campus > Eddington > Girton Interchange.	Underground (~3.2 km) in City centre. Overground from West Campus > Girton Interchange.
2	2022-24	Girton Interchange > Cambourne	Overground. Supports housing growth. Links Cambourne to Cambridge city centre, West Campus, rail station.
3	2022-25	Cambridge Central Rail station > Cambridge North > Science Park > Wing > Newmarket Road P&R.	Underground (~3 km) between rail stations. Serves NE city. Links Science Park to Biomedical Campus.
4	2024-26	'Darwin Line'. Eddington > Girton > Darwin Green > Science Park	Overground. Enables 'Circle Line'. Links West Campus to Science Park. Supports Darwin Green housing. Serves northern villages.
5	2024-26	Granta Park > Haverhill	Overground. Supports housing growth. Links West Suffolk to Cambridge. Supports Biomedical Campus and Biotech cluster.
6	2027-28	Cambridge North > Milton > Waterbeach	Overground. Supports housing growth. Links Waterbeach / Milton to Cambridge. Supports business on A10 and close to Cottenham.
7	2028-30	Cambourne > St Neots	Overground. Links A1 and East Coast Mainline to Cambridge. Supports housing growth Wyboston / Tempsford.
Future		Cambridge North > St Ives > Huntingdon.	Overground. Northern CGB conversion. Extend to Huntingdon.
Future		Newmarket Road > Burwell	Overground. Link Burwell to Cambridge. Potential extension to Mildenhall longer-term.

The 'Isaac Newton Line' would form Phase 1 and follow a route via the University West Campus, city centre, Cambridge Central Rail Station, Addenbrookes, Great Shelford and Sawston.

The 'Isaac Newton Line' has been divided into two practical delivery components (Table 1): Phase 1A is entirely overground and because it includes conversion of the southern Cambridge Guided Busway (CGB) much of the alignment is already in place. This simplifies planning and enables more rapid delivery to operation, which should be possible to achieve within several years from a decision to proceed. Phase1B includes a short bi-directional tunnel within the city centre with several underground stations, and would be more complex to deliver. Phase 1B is essential to 1A because it provides access to the city centre and West Campus, and the two phases need to be considered with an integrated approach, even though it would take more time to construct Phase 1B.

The phases suggested in Table 1 are indicative, and priorities could be adjusted pending development pressures, planning constraints and financing. For example, it may be possible to bring forward phases to run in parallel should factors such as housing needs and available finance allow. Moreover, there may be strategic reasons for advancing one phase more rapidly than another. For example, there is a good case to make strategic connection to major national infrastructure such as the East Coast Mainline, and to link to significant new housing developments such as those proposed at Haverhill, Waterbeach, Wyboston and Tempsford. We therefore anticipate there will be considerable discussion and adjustment of the phases beyond the core backbone of the 'Isaac Newton Line', in this way meeting priorities as they continue to evolve. Our intention here is to set out a general vision for network development, rather than be over-prescriptive in the precise timing and order in which it is delivered. This practical approach allows for flexibility while still articulating an overall network vision and strategy to meet long-term needs.

Cambridge Light Rail is designed to integrate with and support infrastructure developments proposed for heavy rail in the region, including the London – Stanstead – Cambridge and the Oxford – Milton Keynes – Cambridge 'growth corridors'. Over the years, many billions of pounds of investment has been made in the heavy rail network, and it is important to leverage this to maximum advantage. Thus, in developing the Cambridge Light Rail vision, we have carefully considered both existing and planned heavy rail developments so that our proposals will be complementary to, and not duplicative of, investments in the heavy rail network. Thus, while it may appear that gaps exist in the coverage of the Cambridge Light Rail network proposed, these gaps have been considered against the existing heavy rail infrastructure both already in place and planned. The existing heavy rail lines extending to Harston / Foxton / Royston, to Ely, and to Newmarket via Fulbourn are examples of how this existing infrastructure has influenced the scope of the light rail network design. There are opportunities to make improvements to connectivity along these corridors, for example by enabling more frequent stops, through judicious addition of stations, and by improving parking so that the full capacity of the heavy rail network can be more fully utilised.

In addition, we recognise that in some places existing infrastructure may, in the short-term, adequately meet existing needs and there is not an immediate imperative or economic case for wholesale replacement. For this reason, we have not proposed an immediate replacement of the northern section of the CGB, even though we recognise that light rail would represent a superior solution on this corridor. Rather, we suggest replacement of the northern CGB should be considered at a time in the future when its capacity has been reached using bus technology, and also when the time comes to extend a segregated route to Huntingdon.

In contrast, we propose complete replacement of the southern section of the CGB immediately. This section will form a central part of the Cambridge Light Rail network, and replacement at the outset is the only practical means to provide a fully integrated and seamless light rail solution along the full length of the 'Isaac Newton Line'. This proposal has the added benefits that it would expand the capacity, and improve the quality, frequency and operating hours of the public transport services on this line. This would offer major improvements to connectivity at Addenbrookes Hospital and the Biomedical Campus. In addition, we note the CGB is in need of expensive repairs owing to engineering defects, and light rail represents an ideal opportunity to deal with this problem cost-effectively once and for all. Significant funds that would otherwise be directed towards repairs could instead be invested in a permanent and high quality solution using light rail.

For the planned strategic linkages in these corridors to be fully effective, and to maximise the economic leverage and benefits, it is important that intra-city, regional and national transport connections function effectively to cope with the demand, and efficiently service key employment and business centres. In the absence of this integration, and planning as a system, the strategic corridor linkages run the risk of being severely constrained at their intended points of destination.

The approach proposed by Cambridge Connect would provide a **long-term solution** for Cambridge that is both **scalable** in terms of capacity and **extendible** to key destinations as demand and finances allow (Figure 2, Table 1).

Cambridge Connect is coordinating closely with Railfuture East Anglia and UK Tram on these proposals. The concepts have been endorsed by groups such as the Campaign for Better Transport, Rail Haverhill as well as a number of Residents Associations and Parishes. 'Cambridge Past Present and Future' have called for light rail to be seriously considered for the Cambridge region. We are engaging with local and regional organisations and residents to develop the concepts with a view to meeting long-term needs.

It is important to recognise that even shorter-term investments should be planned with a clear vision of the schemes that will be adopted with more substantial funding in the long-term. Otherwise there is a very significant risk they will be strategically disconnected from the longer-term plan, and potentially inappropriate, damaging and wasteful.

We recognise that light rail will require substantial investment, and this is challenging. However, it is important to consider the unique context, the scale and pace of growth, and the strategic and long-term transport needs in Cambridge and the surrounding region. Moreover, we believe that more creative approaches to unlock the funding required may be possible, including initiatives for land value uplift capture, public – private finance partnerships and through national investment in infrastructure that is in the long term strategic and economic interests of the United Kingdom.

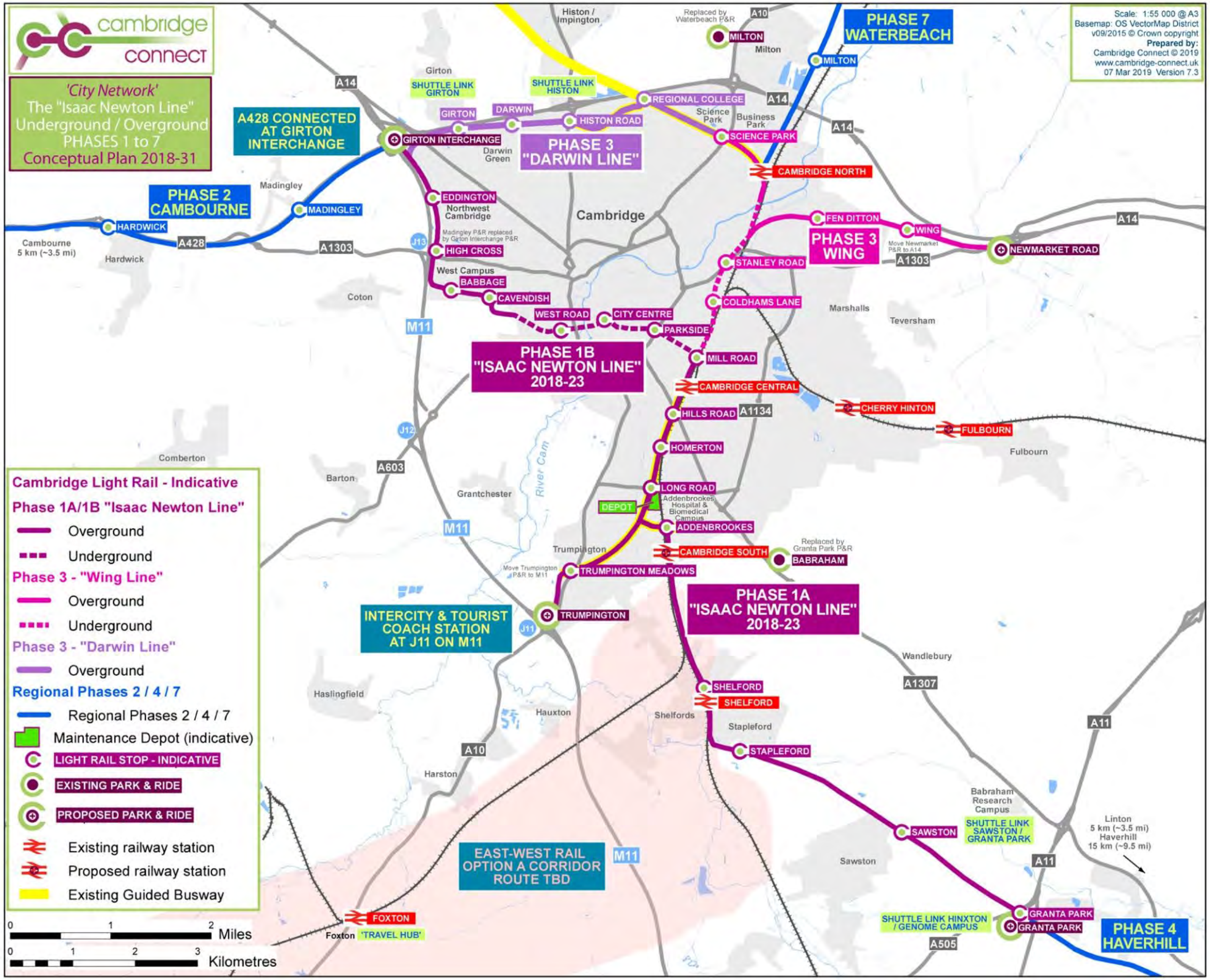

Figure 1 The Cambridge Connect 'Isaac Newton Line' and city network (delivery phases indicative)

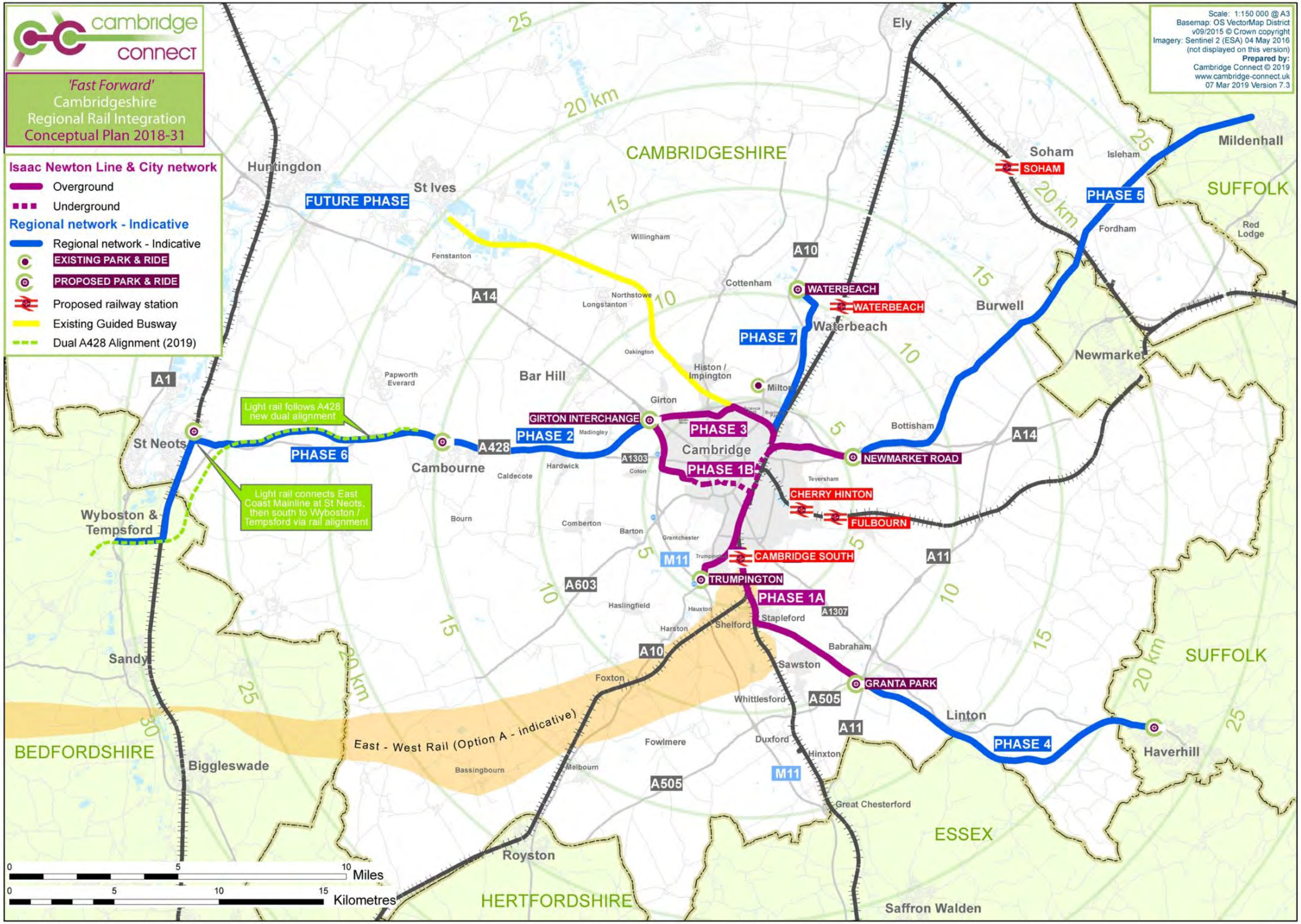

Figure 2 Cambridge Light Rail – Regional network and integration with heavy rail network (delivery phases indicative)

2 Guiding principles

A number of principles have been defined to guide the strategy developed by Cambridge Connect. Those principles, which underpin our 'Greenprint for a Sustainable Future' strategy, are as follows:

1. Responsible investment in our future and in enduring quality for the long-term;
2. Support and strengthen our economy, businesses, productivity and competitiveness;
3. Protect Cambridge's globally outstanding heritage, environment and landscape values;
4. Support environmentally sustainable solutions, including improving air quality, energy efficiency and reduction of waste;
5. Enhance our urban and rural environments as quality places to live;
6. Fast, frequent, reliable and attractive public transport services that foster modal shift;
7. Develop an integrated strategy across modes and across the region, with a network that encourages public transport use and helps support cycling and walking;
8. Phased and affordable delivery of a flexible strategy over time;
9. Long-term balance of capital investment versus operational / maintenance costs;
10. Minimise risk by using proven solutions for successful implementation and service delivery;
11. Encourage competition from suppliers of infrastructure, vehicles and operational services;
12. Meet Office of Rail and Road safety case requirements in a timely fashion for delivery of a practical scheme.
13. Follow existing transport arteries where feasible;
14. Connect the modern University of Cambridge campus;
15. Innovation and vision true to Cambridge.

3 Regional context and background

3.1 Population growth

The Cambridge area is experiencing rapid population growth and the transport network needs to be planned accordingly in order to support jobs, housing, sustainable economic development and to maintain a high quality of life. The population of Cambridgeshire overall is expected to grow by ~24% between 2011 and 2031 (Table 2). The most substantial growth is anticipated to be focused in South Cambridgeshire, where an increase of almost 33% is anticipated over this period. Growth within Cambridge City itself over this period is anticipated to be ~18%.

It is this scale and pace of growth that presents major planning challenges requiring greater investment in transport infrastructure. Radical new approaches appropriate to the scale of transport requirements in the region are needed if economic growth is to be supported. In particular, it is important that transport interventions planned and delivered in the 2020s are fit for purpose to meet the needs in the 2030s and beyond. We believe that a light rail network, coupled with investment in heavy rail and complementary improvements to roads and bus services, represents the strongest package of interventions appropriate to the scale of the challenge. This will require significant investment.

Table 2. Population projections in the Cambridgeshire region 2011 – 2031.

Unit	2011	2031	Increase	% increase
Cambridge City	123 900	146 600	22 700	18.3
South Cambs	148 800	197 600	48 800	32.8
Subtotal	*273 800*	*344 100*	*70 300*	*25.7*
Cambridgeshire	621 300	768 900	147 600	23.8

Data sources: Cambridgeshire County Council Research Group
http://opendata.cambridgeshireinsight.org.uk/dataset/cambridgeshire-population-forecasts-2012

3.2 Housing need and provision

Rapid population growth leads to urgent demand for an increase in supply of housing stock. If supply fails to meet demand, land and house prices will inevitably increase. This trend is apparent in the Cambridge region, with the cost of housing also rising rapidly, forcing many to seek more affordable housing more distant from Cambridge, a process which clearly has implications for the regional transport network.

A range of schemes throughout the region have been proposed, such as those listed in Table 3 below. In addition, major housing schemes have been proposed or are in development in neighbouring areas such as Haverhill, Wyboston, Tempsford, Uttlesford, Great Chesterford, Bassingbourn and so forth. The number of new residents occupying these new housing developments is likely to exceed 120,000 – which is close to the size of the city of Cambridge in 2011. The scale and pace of this growth urgently needs a long-term and strategic transport solution appropriate for the region, for without it we believe the region will suffer negative economic, social and environmental consequences.

Table 3. Housing developments and jobs proposed in the Cambridgeshire region to 2031.[1]

Development	Houses	% Houses	Residents[2]	% Residents	Jobs	%Jobs
Northstowe	9500	19	22800	19	3500	9
Waterbeach Barracks	8500	17	20400	17	5800	14
West Campus / Eddington	3000	6	7200	6	6800	17
Cambridge Northern Fringe	2950	6	7080	6	3600	9
Cambridge East	1700	3	4080	3	1000	2
Cambridge Southern Fringe	4400	9	10560	9	10500	26
Hinxton / Babraham / Granta Park		0		0	5200	13
Bourn Airfield	3500	7	8400	7		
Cambourne West	1500	3	3600	3	2800	7
St Neots East	3700	7	8880	7		
RAF Wyton	3750	7	9000	7		
Alconbury Weald	5000	10	12000	10		
Ely North	3000	6	7200	6		
Cambridge City Centre[3]		0		0	1800	4
TOTALS	**50,500**	**100**	**121,200**	**100**	**41,000**	**100**

1. Greater Cambridge City Deal website retrieved 03 Mar 2016 http://www.cambridgeshire.gov.uk/citydeal/info/2/transport/9/transport
2. Number of residents based on average number of occupants per house = 2.4 (UK average, Office of National Statistics).
3. The City Deal information made no projection for city centre houses, but many are being built.

3.3 Economy, business and productivity

The Cambridge economy has shown sustained and consistent growth over the last 20 years. This has been driven off the back of the strength of the University of Cambridge, which has stimulated and supported growth in the sciences, technology and biotech sectors in particular. The local business organisation Cambridge Ahead has compiled data on this economic success (Table 4).

The strong Cambridge economy is important to the economy of the United Kingdom as a whole. Supporting this economy through appropriate levels of investment in the transport infrastructure is critical to sustainable economic growth not only of Cambridge but also of the UK. For this reason, we consider it appropriate that national-level investment is made in supporting the transport interventions in the Cambridgeshire region.

Table 4. Statistics on Cambridge economy from Cambridge Ahead

Characteristics of the Cambridge economy
• Cambridge is Europe's largest technology cluster.
• ~ 54,000 people employed by more than 4,500 Knowledge-Intensive (KI) firms within 25 miles of Cambridge centre
• Employment proportion in KI activities exceptional at 30%, (cf 12% national average).
• £30bn in annual revenue generated by 20,000 registered companies. More than the City of Manchester.
• 15 Cambridge companies with market capitalisation of more than $1bn[1].
• Employment growth by 7.4% per annum since 2011.
• Third-highest employment growth in UK (15.7% between 2004-2013).
• Cambridge unemployment – one quarter the national average
• Patents: per head 9 times higher than the average of the next 9 highest UK cities.

1. Abcam, ARM, HP Autonomy, AVEVA, blinkx, CAT, Chiroscience, CSR, Domino Printing Sciences, Ionica, Marshalls, Prometic, Solexa, Virata, Xaar

Figure 3 BioMedical Campus & simulated view of new AstraZeneca HQ (Image: AstraZeneca press resources)

The strength of the Cambridge economy is also illustrated by the high concentration of science, technology and research parks, as illustrated in the examples given in Table 5.

Table 5. Cambridge Science / Business Parks – examples of technology employment centres

Babraham Research Campus	Granta Park
Cambridge Biomedical Campus	ideaSpace
AstraZeneca, BioMedical Campus	Peterhouse Technology Park
Cambridge Business Park	St John's Innovation Centre
Cambridge Research Park	University of Cambridge West Cambridge site & Eddington
Cambridge Science Park	Vision Park
Capital Park	Wellcome Trust Genome Campus
Chesterford Research Park	

One simple indicator of regional economic activity related to transport is the level of use of the Cambridge Central Railway Station. Current station footfall is ~12.5 million per year, which is unusually high for a city with a nominal population of 134,000. This footfall has been growing steadlily at about 4.5% per year, and if this continues the footfall at Cambridge Central station could be over 20 million by 2030. By comparison, the cities of Nottingham and Derby have a combined population around four times greater than Cambridge and yet have a combined railway station footfall lower than Cambridge. A share of the activity in Cambridge relates to a high number of tourists visiting by train, although this alone does not account for the scale of difference observed against Nottingham and Derby. Although Nottingham has demonstrably lower demand for public transport by train, the city nevertheless invested in a light rail system and this has been highly successful.

The important implication is that transport interventions in the Cambridge economic context cannot be evaluated on the basis of the city resident population alone. Fundamental demographic, social, spatial, structural and economic factors that underlie true patterns of demand need to be taken into account, and more sophisticated analysis is required before dismissing Cambridge as being too small for a light rail system.

Poor transport infrastructure and connections impact on economic productivity. Congestion and a slow and inefficient transport network results in much wasted time, and this diverts people and resources from more productive activities and uses. Is it a coincidence that productivity in France and Germany exceeds that in the UK, or are their public transport systems – which often include light rail – helping to boost productivity and make their economies less wasteful and more efficient? This is deserving of close study.

3.4 Conservation and heritage

Cambridge is one of the top ten heritage cities in the UK, and the College Backs have been proposed as a World Heritage Site. The values associated with the architecture, heritage and the landscape are of outstanding global importance, and these values need to be fully recognised and taken into account when considering the transport interventions that are necessary to address the pressures of rapid population and economic growth outlined above. The continued expansion of busways and bus lanes within the centre of Cambridge fails to take into account the significant impact this approach will have on degrading the values of the city. Public transport should foster a sustainable city, and this includes sustaining its rich heritage, landscape and environmental values. For these reasons, and for other practical reasons, we propose that the most suitable and solution for public transport in Cambridge must consider inclusion of tunnels. While this will increase the cost, we believe that investment is warranted in view of the outstanding heritage and landscape values.

Light rail is the most suitable technology that is practically deliverable, and that would meet requirements for improvements in air quality, energy efficiency, and conservation of the environment. Moreover, by placing a major public transport service underground, this frees up space on the surface for a safer and more pleasant walking and cycling environment, again encouraging a more sustainable approach to city transport. With a light rail network in place with stops strategically located, this would encourage people to walk or cycle to their nearest stop for longer journeys using public transport.

3.5 Transport strategy

Transport infrastructure developments need to be fit-for-purpose for the region with a planning horizon of 10 to 30 years and beyond. The key drivers of economy, population, demand, education, science & technology, environment & heritage, and social & cultural values all need to be taken into account with a long-term view, and these need to be balanced against the cost and investment needed for future generations. When considered over an appropriate planning time horizon, light rail represents a realistic, attractive and financially viable alternative that would offer many benefits to Cambridge, regional residents and to help facilitate interconnections more broadly (e.g. Stansted and Oxford 'growth corridors' noted above).

3.6 Demand

Population and economic activity drive demand. Preliminary estimates have been made of demand for public transport in Cambridge in 2031 (Table 6). Projections are based on Cambridge City and regional population projections and commuter numbers through to 2031.

Table 6. Potential demand for public transport on light rail in Cambridge 2031.

	Journeys / day (thousand)	Journeys / year (million)	Percentage by Light Rail (%)	Journeys by Light rail / year (million)	Fare (£)	Revenue (£ million)
Commuter	262	96	10	9.6	2.00	**19.1**
Non- Commuter [1]	611	223	5	11.2	2.00	**22.3**
Tourist	28.5	10.4	25	2.5	3.00	**7.8**
TOTAL	902	330		23.3		**49.2**

1. *Cambridge Access Study (2015)*: ~75% of journeys are for reasons other than commuting (health, shopping, education, leisure etc). Therefore 70% of journeys are assumed Non-commuter.

It is estimated that demand could be around 3500 – 4000 journeys per hour on a single central city light rail line at peak. Light rail is considered an ideal mode of public transport for demand in the region of "3000-11,000 pax per hour" per direction (International Union for Public Transport (UITP)). With one light rail line and almost 8000 pax/hr at peak, this equates to almost ~4000 pax per/hr per direction at peak, assuming 15% of commuter journeys undertaken by light rail. Thus, demand on the 'Isaac Newton Line' could meet the criteria for an "ideal" level of demand set out by the UITP. Many European cities with light rail (e.g. Lausanne, Freiberg) achieve a much higher usage of public transport.

Around five million tourists visited Cambridge in 2016, and we are confident that tourists would be an important demand segment for the 'Isaac Newton Line'. This is particularly the case because the line would link the central rail station to the heart of the city. A proposed intercity / tourist coach station at the M11, and from other Park & Ride facilities, would also link to the city centre.

More work is needed on demand and growth projections, although at this stage we note that the projected total number of journeys on Cambridge Light Rail by 2031 (23.3 million) given in Table 6 is less than the 28 million journeys that are made annually on the M2 line of the Lausanne network (2014 data), which is a comparable situation to Cambridge.

4 Proposition

4.1 The network backbone: 'Isaac Newton Line'

The 'Isaac Newton Line' would substantially address transport needs along a key strategic axis in Cambridge, linking the newly developed and rapidly expanding University of Cambridge West Campus and Eddington centres with the central rail station and city centre, the biomedical campus at Addenbrookes and to important bioscience campuses in the Granta Park, Babraham and Hinxton region.

The 'Isaac Newton Line' would:

- Provide a light rail 'backbone' extending though the heart of Cambridge from Girton Interchange in the northwest to Granta Park in the southeast, keeping the City 'Open for Business';
- Provide a direct link with the proposed A428 Expressway at the Girton Interchange, providing connection between the highway extending east-west between Oxford and Cambridge and a high quality, reliable, frequent and fast public transport system accessing the city centre and key employment hubs;
- Integrate with the heavy rail network at Cambridge Central Rail Station and at the proposed new Cambridge South Station, providing a public transport solution future-proofed for East-West Rail developments that takes into account the likely specific alignments;
- Provide multimodal links to bus / coach and Park & Ride services at key interchanges – for example the A11 / A505. Similar multimodal links would be provided at Junction 11 on the M11 / A10 and at the Girton Interchange on the A428 / A14 / M11. These links would provide improved regional integration with a reliable, fast and frequent public transport into the heart of Cambridge;
- Provide a reliable, fast and frequent link between the three University of Cambridge campuses, which currently are poorly interconnected. Good connections between the campuses in Cambridge would strengthen University integration and overall educational and business connectivity in the region;
- Relieve vehicle traffic pressure on the road network by attracting people onto the light rail and heavy rail routes, reducing the need for road network capacity expansion;
- Provide a strategic backbone of public transport that enables phased extensions to nearby and more affordable housing in residential and employment centres such as Cambourne, Haverhill, Fulbourn, Waterbeach, St Neots, etc;

- Establish an Intercity Coach Station at a new Park & Ride at J11 on the M11, which would enable tourists and others to travel into Cambridge from the periphery without congestion and reduce the need for large coaches to travel into the city centre;
- Encourage walking / cycling from nearby residential areas and employment centres to strategically located stops on the public transport network;
- Foster a more sustainable city, protecting its rich heritage and environmental values, with electric light rail eliminating emissions at the street and being vastly better for air quality.

4.2 Development in Phases and time-frames

Any Cambridge Light Rail scheme would take time to resource and to implement, with detailed advance planning and design needed. The Combined Authority, working in coordination with the GCP, has the opportunity to make substantial progress. The GCP finance agreement requires demonstrable economic impact from measures undertaken, and light rail developments have a history of generating economic benefits (e.g. the Docklands Light Railway (DLR)). Long term, these extensions and connections will help to create a more integrated and sustainable economy in the region, and enhance the economic strength of the United Kingdom.

Cambridge Light Rail can be delivered in a series of manageable and affordable stages over a period of around 10-12 years. The phases identified at this stage are as follows:

Phase 1: the 'Isaac Newton Line', Phase 1, is viewed as the 'backbone' of public light rail transport that would be expanded in phases as need, demand and finance allow (see Figures 1 and 2, and Table 1).

Phase 2: there could be an early need for extension to Cambourne in view of planned housing developments and to meet local planning obligations. Initially, it may be possible to provide an effective connection between Cambourne and the 'Isaac Newton Line' at the Girton Interchange by running a bus service along the A428. As housing is expanded, and perhaps influenced by other developments near St Neots (e.g. Wyboston, Tempsford), light rail from the Girton Interchange to Cambourne and beyond could be extended quite quickly.

Phase 3: would serve residents and business in the Mill Road / Coldhams Lane / Newmarket Road areas, connect with Cambridge North rail station and the Science Park, and include a spur on the old rail alignment to Fen Ditton and the Wing development, extending to the A14 where it is proposed that the existing Park & Ride would be relocated.

Phase 4: would connect the Science Park to Eddington and the West Campus, following the route of the current guided busway and via the planned housing development at Darwin Green. Dubbed the 'Darwin Line' this route would serve commuters from villages to the north of the city and create an integrated 'circle line' across the city (Figure 1).

Phase 5: Haverhill is not presently served by a rail link. There are safety and congestion issues on the A1307 highway, and a relatively large population at Haverhill, many of whom work in Cambridge. There is strong interest in Haverhill to re-establish the rail link, and over 6000 people have called for its reinstatement. A light rail link to Haverhill would support planned housing growth, and would also support key workers at Addenbrookes and the Biomedical Campus with access to more affordable housing.

Phase 6: substantial housing development is projected in this area and a light rail link would be warranted when this reaches fruition. In the near-term, Waterbeach may be served by the heavy rail station.

Phase 7: extension from Cambourne to St Neots would link Cambridge to the East Coast Mainline and A1 strategic corridor, as well as housing growth centres in this area.

Expert work on technical and economic feasibility studies to develop a detailed set of realistic and properly costed options for a scheme would take around a year. Much work has already been completed as part of the Strategic Outline Business Case for CAM (Steer 2019). We anticipate this work will be continued through 2019 to produce a full Outline Business Case for CAM. With subsequent commitments, detailed engineering design could commence in 2020, and it might be feasible to commence construction of the Isaac Newton Line in 2021 with a view to completion of Phase 1A in 2022 and Phase 1B in 2024. Further phases could be staged, or constructed in parallel, as appropriate and as finance and practicality allows. It could be realistic to complete a Cambridge Light Rail network by 2025 – 2031 depending on priorities and phasing.

Crossrail tunnelling progressed at an average rate of ~38 m /day. If the underground component of Cambridge Light Rail was ~6 km (Phase 1B and Phase 3), and we assume twin bore tunnels constructed in a similar manner to Crossrail, tunnel construction for the network could be completed in ~315 days (~10 months).

The time-frame for phases is subject to a wide range of influences, including the level of public engagement and support, political and institutional support, technical engineering, economic appraisal, financial mechanisms, and environmental and social impact assessments, to name a few.

The full Cambridge Light Rail scheme is longer-term by nature, and yet many needs are pressing. Some interventions, such as enabling an all-ways junction at the Girton Interchange, could be progressed immediately, and this would provide short term benefits on the road network. At the same time the investment would be good for the long term strategic potential of the overall transport network, including for mass transit and for the wider connections planned to Oxford.

In addition, as improvements are made to heavy rail lines (e.g. upgrades to the Newmarket line, East – West Rail), new stations could be provided at Cherry Hinton and Fulbourn (Figure 1) to serve residents and businesses in this area. In addition, parking facilities could be improved at a number of existing regional stations (e.g. Foxton) to leverage more fully the capacity that already exists on the heavy rail network and to encourage more people to use these services.

4.3 Technology

Vehicles

Light Rail Vehicles (LRVs) and trams are essentially interchangeable; the difference is that the former typically run on segregated routes while the latter typically share road space with other vehicles. Many lines are a combination of segregated and shared routes, and the same vehicle runs on both. LRV / tram technology is highly evolved and widely implemented across the world. It is well-tested and suitable for implementation in a range of situations. Modern LRVs typically operate at maximum speeds of around 70-100 km/h, and employ regenerative braking technology to harness energy when brakes are applied, increasing energy efficiency. These modern vehicles should not be confused with the rickety old trams that once upon a time rattled along streets and were phased out. Modern trams are sophisticated, fast, smooth, practical and comfortable.

The LRV industry is large and well-established, providing a highly competitive marketplace for procurement and a reliable source of back-up engineering support and spare parts. For example, Alstom alone has sold more than 2300 Citadis LRVs to more than 50 cities in 20 countries worldwide, demonstrating the proven nature of the technology. Other major LRV manufacturers such as Bombardier, CAF, Siemens, Stadler, Hitachi, etc. have supplied thousands of high quality and reliable vehicles, and new entrants to the market are rapidly emerging from China and Asia.

Figure 4 Bombardier Flexity Light Rail Vehicle 2016. Photo: © Bombardier.com 2016.

Traditionally, trams are powered by electric overhead lines (catenary). However, many trams, such as Alstom's Citadis X05, now employ fast-charge batteries to power the vehicle so it can operate between stops without catenary, enabling protection of sites of high landscape or architectural value from visual intrusion. This can also reduce investment costs, help preserve trees along route, and enable better access for emergency services (e.g. fire ladders) in built-up areas. A range of battery technology solutions are available, with a number of charging methods employed. For example, some charge on-board batteries within 20 s when the trams are at stops, while others charge less frequently but with longer run-times. Birmingham trams are being converted to catenary-free. On the other hand, catenary can offer the advantage of constant power delivery, which should a technical problem emerge can be useful for vehicle recovery. Inside tunnels there are no immediate aesthetic reasons to eliminate catenary. Technical analysis of the most cost-effective option for Cambridge Light Rail has yet to be undertaken, although in view of the pace and benefits of battery developments, it seems likely at this stage that a solution suited to Cambridge might, at least in part, be catenary free.

Catenary free operation is present in numerous systems worldwide using different methods. For example, a subsurface contact point along the length of the system is used in the historic city centre of

Reims (France). This method works well, although is relatively expensive to install and to maintain. Most other catenary free systems use battery technology, most of which are similar and use lithium battery packs to power trams with charging points at stops and termini. The charging points are usually short lengths of catenary wire which charge the battery pack through a pantograph. Charging may take place at all stops whilst the vehicle is static, or at several stops along a route, and certainly at termini during turnaround time. The batteries are also topped up to some extent by recharging from motion of the vehicle and braking regeneration.

Seville uses trams with a combination of batteries and super-capacitors which charge under short catenary lengths at each stop. The charging at each stop allows a smaller battery pack to be used, which reduces the weight of the required batteries. Almada (Portugal) operates trams over 2.5 km between charging points using a supercapacitor system. China has been developing catenary free systems in collaboration with Siemens, and opened a system in Huai`An in 2016 that extends over 21 km and operates with batteries re-charging at stops.

Figure 5 Nottingham NET Bombardier Flexity Tram is accessible. Photo: © Paul Hollinghurst 2010.

Battery technology is still in its development phase and continues to improve. Currently battery life is fairly short and is determined by several factors such as gradients, speeds, weight and battery age. The batteries deteriorate over time, and need to be kept at 60–90% charge during operation to maintain optimum operating level and slow the rate of degradation. Because of this requirement, the distance between charging points cannot be too great to prevent running down the battery packs.

Catenary free LRVs are more expensive than standard LRVs due to the additional traction equipment and battery packs. This equates to ~£500k per vehicle (Birmingham tram network cost). There are savings to be made by removing the need for catenary implementation, although this will vary depending on the type of battery, terrain etc. and the requirement for charging points. In effect, there is no saving in terms of power system i.e. feed from the grid and sub stations, but the saving is on building the catenary structures. An additional cost has to be factored in for battery pack replacement over time, hence the saving against catenary operations diminishes due to replacement costs. It is likely however that as battery technology improves this cost will be reduced.

OverHead Line Equipment (OHLE) is expensive to erect and requires regular maintenance, although this tends to be monitoring rather than expensive intervention. OHLE construction varies according to terrain, offstreet / on street, subsurface conditions, etc. Given all these factors it should be possible to save between £500k and £1m per km through adoption of a catenary-free system, still allowing for provision of short sections of OHLE for charging and substations for provision of power.

Number of vehicles

The number of LRVs required would vary with network length, service frequency and speed. Passenger numbers are primarily driven by frequency, reliability, comfort, safety and speed.

A consistent level of service frequency right across the network is desirable and simplifies operations, although may be difficult to sustain outside of the city network where demand would be lower. This would also increase the number of LRVs required, increasing both capital and operational costs. On the other hand, different service frequencies between city and region complicates timetabling and vehicle allocation, and may also require construction of additional sidings or crossovers.

At this stage, we have assumed that different service frequencies between city and region are more likely, and Cambridge Connect has made an initial estimate of the number of LRVs required given a service with a 5 minute headway within the city and a 20 minute headway in the regions. In this model, the regional services would also serve the city, and additional LRVs operating city-only would increase city headway. We have estimated that when the full regional network was complete with two main lines extending from Haverhill to St Neots and Trumpington M11 to Waterbeach, a fleet of around 30 LRVs would be required to maintain this service level.

In practice, Cambridge Light Rail would be delivered in phases, and for this reason a full fleet would not initially be needed. Phase 1 would have a fleet requirement of ~14 LRVs (plus spares) to provide a service frequency of 5 minutes. A further 8 LRVs would be required to provide a service frequency of 5 mins for Phases 3 and 4 (ie. complete city network). An additional 3 LRVs would be needed to provide a service frequency of 20 mins to Cambourne and Haverhill in Phases 2 and 5, with a further 2 LRVs needed for Phases 6 and 7. The total daily service requirements would be ~27 LRVs, and with 5 reserves (15%) this would suggest a fleet of 32 LRVs required for the complete Phase 1 to 7 network.

These estimates are indicative, and have been made to provide input to the cost assessment in Chapter 7 on a phased delivery timetable. In due course, a detailed examination of runtimes, dwell, specific vehicle technologies (e.g. catenary-free etc) and other factors would be needed to estimate LRV requirements. In practice, this would be undertaken phase by phase.

Configuration of vehicles

A wide range of tram configuration is possible, from around 20 m to over 40 m in length, and accommodating from ~100 to over 300 passengers per tram. There is a trend towards smaller trams as an alternative to busways for medium sized cities, and compact trams have been adopted in cities such as Avignon and Aubagne.

LRVs may be configured as 'Low floor' or 'High floor'. High floor LRVs require additional platform infrastructure to allow easy access at stops, increasing costs. Low floor LRVs are designed to provide good accessibility for the disabled, children, and for pushchairs etc., are more cost-efficient, and should be selected for a new build system.

Light rail vehicle costs

Modern LRVs can vary considerably in cost. For example, Manchester Metrolink vehicles were procured for £2.1m each on average, although they have a slight premium because they are high floor. Since that procurement, construction regulations have been enhanced and those vehicles would now cost ~£2.5m each. Taking into account the potential costs of battery provision, we estimate that LRVs today could be acquired for ~£3m each. Cambridge Connect has therefore assumed a base cost of £3m per unit as a realistic working estimate to substantiate overall costs. Tram specification and configuration also influences cost, with the number of articulation units and bogeys being two significant drivers, so more work needs to be done before costs can be more precise.

Vehicle maintenance facility / depot

LRV maintenance requires a depot of sufficient size for the eventual fleet to be used on the expanded network. Initially, a smaller facility could be built, which would be expanded as the network grows. This approach allows the facility to be upgraded in line with new and emerging technologies as the network develops. It is important at the outset to select a site that has sufficient areal capacity for the anticipated future expansion. The facility should allow for provision of office space for network management, engineering facilities and for inclusion of essential machinery such as a wheel lathe.

Indicative costs for developing a depot for 40 trams is approximately £45m (evidenced by the maintenance facility in Dublin for the LUAS system). Costs may vary if, for example, OHLE covering only part of the stabling area is built, although it would probably be better to provide full coverage to allow all vehicles to recharge overnight if battery trams are procured. Based on the number of trams estimated as initially required for the 'Isaac Newton Line', a maintenance depot would initially cost up to ~£30m.

Cambridge Connect has provisionally identified several potential sites for a depot: one is indicated near Long Road / Addenbrookes (Figure 1), and other possibilities such as near Sawston could also warrant consideration. These sites are identified on the Isaac Newton Line in anticipation that this would be the first phase to be developed, and the depot will need to be accessible from the outset. A detailed assessment of potential sites has not yet been completed.

Utilities diversions

Utility diversions need to be considered, especially when building tramways through listed environments or through areas which probably have a high propensity for older, maybe Victorian, utility systems. Utilities diversions have typically been necessary due to the concerns of degradation from stray current associated with electrified systems. These concerns may be more limited should the scheme select battery operated LRVs, although this aspect needs more detailed consideration. Irrespective of the mode of operation, it is advisable to divert utilities as appropriate in order to minimise interruption of transport services, and also to allow ease of access to utilities installations for maintenance, repair or renewal.

By way of example, in Manchester a Victorian sewer collapsed on the second city crossing, which had to be renewed and many utilities had to be diverted due to a lack of space near the tramway. The provision of inspection tunnels added to costs where utilities were left in the tramway but with access for regular inspection provided without impacting on tram services.

Utilities diversions have the ability to escalate costs through construction and time delays and the costs cannot be accurately estimated without full utility surveys. Surveys are also necessary because it is common for unchartered utilities to be uncovered, which can also impact on cost and time. In Manchester, the authority took utility risk insurance to mitigate the risk of price escalation by construction bidders.

Several features of the 'Isaac Newton Line' suggest that the costs of utilities diversions should remain manageable. First, 20 % of the alignment comprises the existing busway and it can be assumed that most of the utilities diversion costs were dealt with at the time of busway construction. Secondly, ~12 % of the line would be underground and beneath a level at which services are encountered. Thirdly, ~60% of the line runs in agricultural areas bordering the West Campus and towards Granta Park. That is, ~90 % of the line passes through areas of relatively low risk of encountering services. This is in contrast to many light rail projects which run their full length sharing roadways at the surface, where utilities are typically concentrated.

Clearly, an allocation of cost must be allowed for dealing with utilities, although in the case of the 'Isaac Newton Line' we consider this should not be unduly inflated.

Tunnelling

At this stage it is estimated that the tunnel required for the Isaac Newton Line would be ~3.2 km in length, bi-directional, with each bore being approximately 4.5 to 5.0 m in diameter, which is generally regarded as the average required for underground metro tunnel bores. A second tunnel of ~2.9 km extending from near Mill Road to Cambridge North station is proposed at Phase 3, which in practice might be directly connected with the tunnel on the Isaac Newton Line. In total, we propose tunnelling of ~6.1 km, and because the tunnels are bi-directional this equates to 12.2 km of single bore tunnel.

A 5.0 m tunnel diameter is suitable for a single track and provides enough space for a protected escape walking route in the unlikely event that passengers have to be evacuated in an emergency or if a vehicle breaks down. This will, of course, need to be refined in regard to vehicle sweep path and tunnel curvature to enable the diameter to be fixed. The 5.0 m diameter could also accommodate OHLE if required. Being underground, and in a fully segregated space, an opportunity may present for battery charging via OHLE with no impact on the urban environment. OHLE in the tunnel could also make recovery of a broken down vehicle (unlikely but worthy of consideration) much easier.

World-class tunnelling expertise exists in Cambridge (e.g. Centre for Smart Infrastructure and Construction at Department of Engineering, Mott MacDonald, Atkins, Skanska, etc.). One of the world authorities on tunnelling is Professor Lord Robert Mair (CBE FREng FRS), who is Sir Kirby Laing Professor of Civil Engineering and Head of Civil and Environmental Engineering at the University of Cambridge. He has been involved in a wide range of rail tunnelling projects worldwide, including being closely involved with the design and construction of the Jubilee Line Extension for London Underground, the Channel Tunnel Rail Link, and Crossrail projects. Prof Mair assessed the thick gault clay deposits that underlie Cambridge as being "ideal" for tunnelling.

London Bridge Associates gave a tunnelling cost estimate of £50.7m per linear km of single bore tunnel (Steer Davies Gleave 2018), which equates to ~£101m per linear km of twin-bore tunnel, which included 15% design costs and 64% optimism bias.

The London Bridge Associates estimate above provides a base cost of ~£54m per km for a twin bore tunnel excluding design costs and optimism bias. In view of Cambridge clay being assessed by Prof Mair as an 'ideal' tunnelling medium, even better than London, we have applied 40% as a premium to cover design and optimism bias in our costings. Thus, £75.6 m per linear km of twin bore tunnel has been used as the basis of our tunnelling cost estimates.

Future technological development

Light rail technology is fast-evolving, and even more technologically advanced vehicles are likely to be available by the time Cambridge Light Rail might become operational (~2023). For example, driverless vehicles – much heralded as the 'next big thing' on our roads – are already in operation on London Docklands Light Railway, and elsewhere. Sophisticated control systems ensure the network operates smoothly, quickly, reliably and safely. It seems plausible that driverless systems, and innovative catenary-free light rail vehicles, might be standard by 2023.

Automated light rail systems have been implemented in various locations such as Dubai and in London on the Docklands Light Railway (DLR). Additional command and control systems are required and presently automated operation is only suitable on fully segregated routes. Future technical development in autonomous systems may soon allow automated operation in an urban environment with local traffic, cyclists and pedestrians, just as this is envisaged for driverless car operation. The timing of practical delivery of this technology is uncertain, with estimates ranging from a few years to at least a decade.

Looking further to the future, passive magnetic levitation is an emerging technology that promises to bring down the cost of maglev to a practical level. While traditional maglev has been around several decades, and is in routine operation in Japan and China, the technology has not been widely adopted owing to cost and complexity. However, it appears that passive maglev, which uses a different method to achieve levitation, might become viable at lower cost. This technology has already been successfully demonstrated by Virgin and other groups working on versions of the 'Hyperloop' system. While this technology remains in the future, the route network proposed by Cambridge Connect is future-proofed to accommodate emerging technologies such as these.

4.4 Case studies

It has often been said that Cambridge is too small for an underground or a light rail public transport system, and that it would be unaffordable. But is this claim true? On what evidence are these claims based? Are there examples of light rail systems serving cities comparable in size to Cambridge, and how successful are they? Cambridge Connect has examined examples of light rail systems operating very successfully in cities of comparable size throughout Europe, bringing very positive benefits.

Many successful LRT networks exist in small-to-medium sized cities, and they are common in Germany and France. For example, Table 7 lists 19 small-to-medium-sized cities in France with light rail or tramways, with Cambridge included for comparison. It may not be commonly proposed for cities of this size in the UK, although this does not imply that they cannot be successful.

Complex spatial, structural, demographic, cultural and economic factors underlie light rail implementation patterns, and caution should be exercised in drawing over-simplistic conclusions based on populations alone. For example, Valenciennes has a population of only ~43k, and yet it has an extensive light rail network with ~34 km of track and 48 stops. According to Steer Davies Gleave (2018), this should be unsupportable, until it is understood that this light rail network serves a dispersed cluster of communities with a combined population of ~390k people. The Valenciennes context is more similar to Cambridge than simple populations alone imply.

Another example is Orléans, with a population of ~115k and yet a network of ~30 km in length and 49 stops. With its system length per head of population similar to that proposed for Cambridge, this is quite similar to the light rail network proposed for Cambridge.

Lausanne, Switzerland, is an example of a city with light rail and an underground system. Lausanne has a population and land area similar to Cambridge; other comparable aspects include two universities, a teaching hospital, high-tech industry and a wide commuting basin. A key difference, however, is that Lausanne has excellent public transport on a very successful underground light rail metro, with annual ridership of ~41m (includes ridership on the integrated bus system).

Table 7. Medium-sized cities in France with light rail / tramways[1]

City	Lines	Stations	Length (km)	Popn	Length / person (m)
Reims	1	23	11.2	182,592	0.061
Le Havre	2	23	13	172,074	0.075
Saint-Étienne	3	38	11.7	172,023	0.068
Grenoble	5	71	36	160,215	0.225
Dijon	2	35	19	153,003	0.124
Angers	1	25	12.3	150,125	0.082
Cambridge (City)	2	31	36	146,700[2]	0.245
Le Mans	2	35	18.9	144,244	0.131
Clermont-Ferrand	1	34	15.9	141,463	0.112
Brest	1	28	14.3	139,386	0.103
Tours	1	29	15.5	134,803	0.115
Besançon	2	31	14.5	116,952	0.124
Orléans	2	49	29.3	114,375	0.256
Mulhouse	3	29	16.2	112,063	0.145
Rouen	1	31	15.1	110,755	0.136
Caen	2	34	15.7	107,229	0.146
Nancy	1	28	11.1	104,072	0.107
Avignon	1	10	5.2	90,305	0.058
Aubagne	1	7	2.8	45,303	0.062
Valenciennes	2	48	33.8	42,851	0.789

1. Bouquet, Y. 2017. The renaissance of tramways and urban redevelopment in France. *Miscellanea Geographica* **21** (1): 5-18.
2. Population is projected to 2031 (data from Cambridgeshire County Council Population Research Group 2014) to take into proper account the strategic planning horizon.

The Lausanne light rail system currently comprises two lines. The network extends ~14 km, of which about half is underground. The 7.8 km, mainly overground, M1 line with 15 stations opened in 1991. The 5.9 km long fully automated, driverless, M2 line opened in 2008 and is mainly underground. It has 14 stations, and the M2 line alone has an annual ridership of ~28m. Patronage of the metro has far exceeded expectations, and as a result of this success the public have voted to build a third line, which is to be opened in 2018. The metro has transformed public transport in Lausanne, with both bus and tram usage increasing by 10–15% since 2010. The proportion of commuters using public transport in Lausanne is

Figure 6 Lausanne light rail. Image: 'Marmelade' 2007 (Public domain, Wikipedia).

around 40%; this compares to ~8% in Cambridge (excluding heavy rail), where the bus service is slow and unreliable. More detail on the Lausanne Case Study, prepared by Kevin Rathbone of Cambridge tech company Robotae, is available from the Cambridge Connect website.

Grenoble has a light rail system length of 36 km and today has a population similar to that which Cambridge is projected to attain in 2031. The system has five lines and 71 stops, providing the city with a very well-connected public transport backbone using light rail. According to Steer Davies Gleave (2018), this network should not be viable, and yet it is extremely successful, which calls into question the basis of their analysis. Avignon has a small population ~95k, and yet has managed to implement a light rail line of 6 km with 10 stops. Avignon is designated a World Heritage Site by UNESCO, and given Cambridge also has globally significant heritage values this city may also represent an interesting model for comparison.

These are a few of the numerous examples that warrant in-depth analysis to inform decisions about public transport options in Cambridge. Within the scope and budget for this report, we are not able to go into further depth here, although it should be apparent that there are many examples of cities comparable to Cambridge where light rail has been very successfully implemented. These few examples demonstrate that the proposition that Cambridge is either too small, or too poor, to implement light rail must be seriously questioned. It is clear that a range of cities of a size and with economic and cultural circumstances similar to Cambridge, particularly our nearest neighbours in Europe, have been able to afford – and have decided to implement – high quality light rail systems. This cannot be denied and should not be ignored. Detailed case studies should be undertaken in comparable cities in France, Germany, Switzerland, etc., and these should be carefully benchmarked against the Cambridge Light Rail proposals. The experience offered by such case studies should be used to guide development of the public transport system in Cambridge, and indeed in the UK more generally.

5 Benefits

5.1 Journey times

Cambridge Light Rail would provide short journey times, faster than by car without traffic, more predictable, and no need to park. Based on an average speed of 33 kph (London Tube, Transport for London) *including* stops, the proposed routes could move people across Cambridge quickly (Figure 7). Typical journey times between example stops are:

- Cambridge Central Station to City Centre: ~4 mins. Two stops: Mill Road, Parker's Piece.

- Histon Road (near A14) to Market Square: 15 mins via Eddington / West Campus.
- Cambridge Central Rail Station to Addenbrookes: 5 mins. Three stops.
- Cavendish to Addenbrookes: 13 mins. Eight stops.
- Full length of Isaac Newton Line (Girton Interchange to Granta Park, 20 km): ~28 mins .

The journey times on a Cambridge Light Rail system could be comparable to the London Tube provided dedicated lines are used. A network running on streets shared with traffic would result in slower journey times. Detailed studies remain needed to give more accurate speeds and journey times.

For comparison, consider the journey from Cambridge Central Rail Station to Market Square. A bus journey would first take ~10 mins to Drummer Street, and then the 450 m walk to Market Square would take 6 mins, giving 16 mins in total. This is four times longer by bus / walk than by light rail, which would be 4 mins including stops (assuming the city centre stop is near Market Square)**.** However, bus times are subject to congestion, so in practice bus journeys would often take much longer, while journeys on light rail would be reliable. Passenger exchange rates on Light Rail Vehicles are much faster than on buses, which reduces stop-time required at stations thereby increasing overall journey speeds.

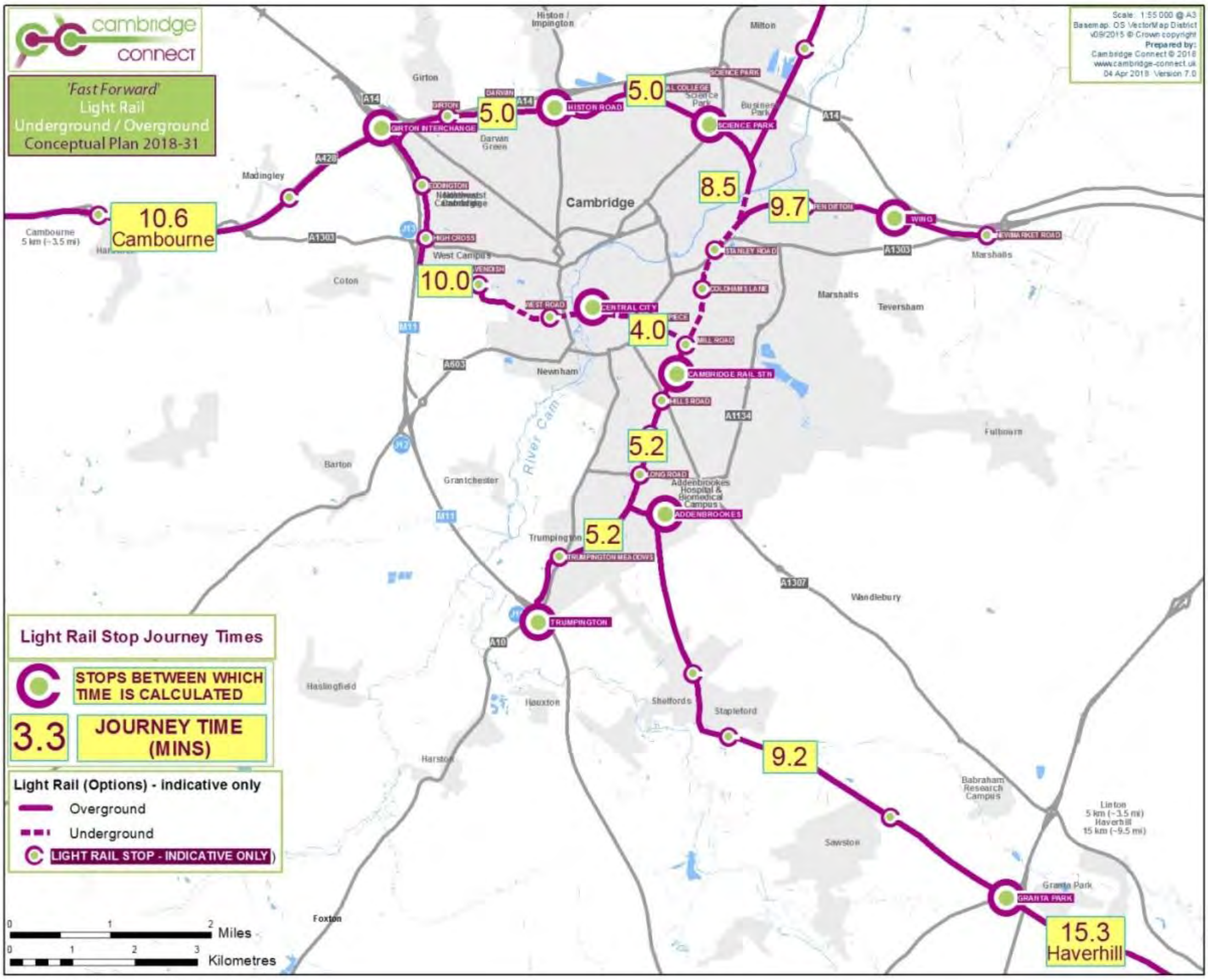

Figure 7 Journey times between example stops on Cambridge Light Rail network.

5.2 Frequency, reliability and convenience

A fast, frequent, reliable and efficient Cambridge Light Rail service would be much more convenient for people. This would have a major influence on travel mode choices. Cambridge Light Rail stops would be located at convenient junctions, coupled with Park & Ride facilities where appropriate on the periphery of or more distant from the city. Importantly, the stops are located so they would be very accessible to the Cambridge cycle network. Light rail on dedicated lines would be faster, more frequent, more reliable, and more predictable than other options.

5.3 Accessibility

Walking and cycling

The accessibility of the proposed Cambridge Light Rail stops to residential / commercial areas in Cambridge is illustrated in Figure 8. The percentage area of the City that is accessible on foot and by cycle to light rail stops is summarised in Table 8. The map shows an accessible and attractive public transport alternative that could be transformative for inner city traffic, as more people decide to walk or cycle to their nearest stop and, instead of driving their car, use the light rail network to reach their destination. This is a 'Greenprint for a Sustainable City'.

Table 8. 'Greenprint for a Sustainable City': network accessibility by walking and cycling

Distance to stop (m)	Walk time to stop (mins)	Cycle time to stop (mins)	City area accessible (%)
500	6	3	30
1000	12	5	69
1500	20	8	90

Included in the above calculations are the built-up areas of Cambridge City, Grantchester, Coton, Girton, Histon, Milton, Fulbourn, Trumpington, Hauxton, the Shelfords, and Sawston. Non-urbanised land on the periphery of the Cambridge City yet within the City boundary was not included in the accessibility calculations to provide a more realistic assessment of how close the stops are to residential, commercial and employment areas. The northern villages close to the A14 were included in accessibility calculations because of their proximity, their important commuter role, and because of the traffic they generate for the A14 and along principal arterial routes into Cambridge, particularly on Histon and Milton Roads.

The vehicle design, with low floors and wide doors, allows bicycles to be taken on board. This has been adopted in Amsterdam and Edinburgh with success. It might also be feasible to allocate space in LRVs for bicycles in Cambridge, and the practicalities should be investigated as the scheme is developed.

In their assessment of the Cambridge Connect proposals, Steer Davies Gleave (2018) concluded the in-scope population catchment of the Cambridge 'city' light rail network would house ~60,000 people within 500 m of a stop. The report suggested this was "45% lower than the average of all UK [light rail] systems, despite a total network length 21% longer". The "in scope" population within 500 m of a stop in

Cambridge city is broadly in line with our calculations, although we question whether 500 m is a useful comparator in the case of Cambridge.

Data show that a high proportion of people travel short distances by cycle in Cambridge (~30 % of commuting), and this is likely to influence significantly the distance at which stops on the network are considered "in scope". This makes Cambridge substantially different to other cities in the UK, and in particular to those cities cited as comparisons in Steer Davies Gleave (2018).

To calculate the number of people "within scope" in the Cambridge context, we suggest it is more appropriate to use (for example) 1000 m (a 12 min walk, or 5 min cycle ride) because high cycle usage alters the assumptions made about the accessibility of stops. Should this be the case, which seems plausible, then the "within scope" population rises to ~100,000, or ~67 % more people within easy reach of a stop than suggested in the Steer Davies Gleave (2018). This is important, because it illustrates that simple calculations or incorrect assumptions about accessibility can have a dramatic impact on the size of the population (i.e. demand) that lies 'within scope' of the network. More work is needed on these aspects, although this brief explanation illustrates some of the issues that need to be taken into account.

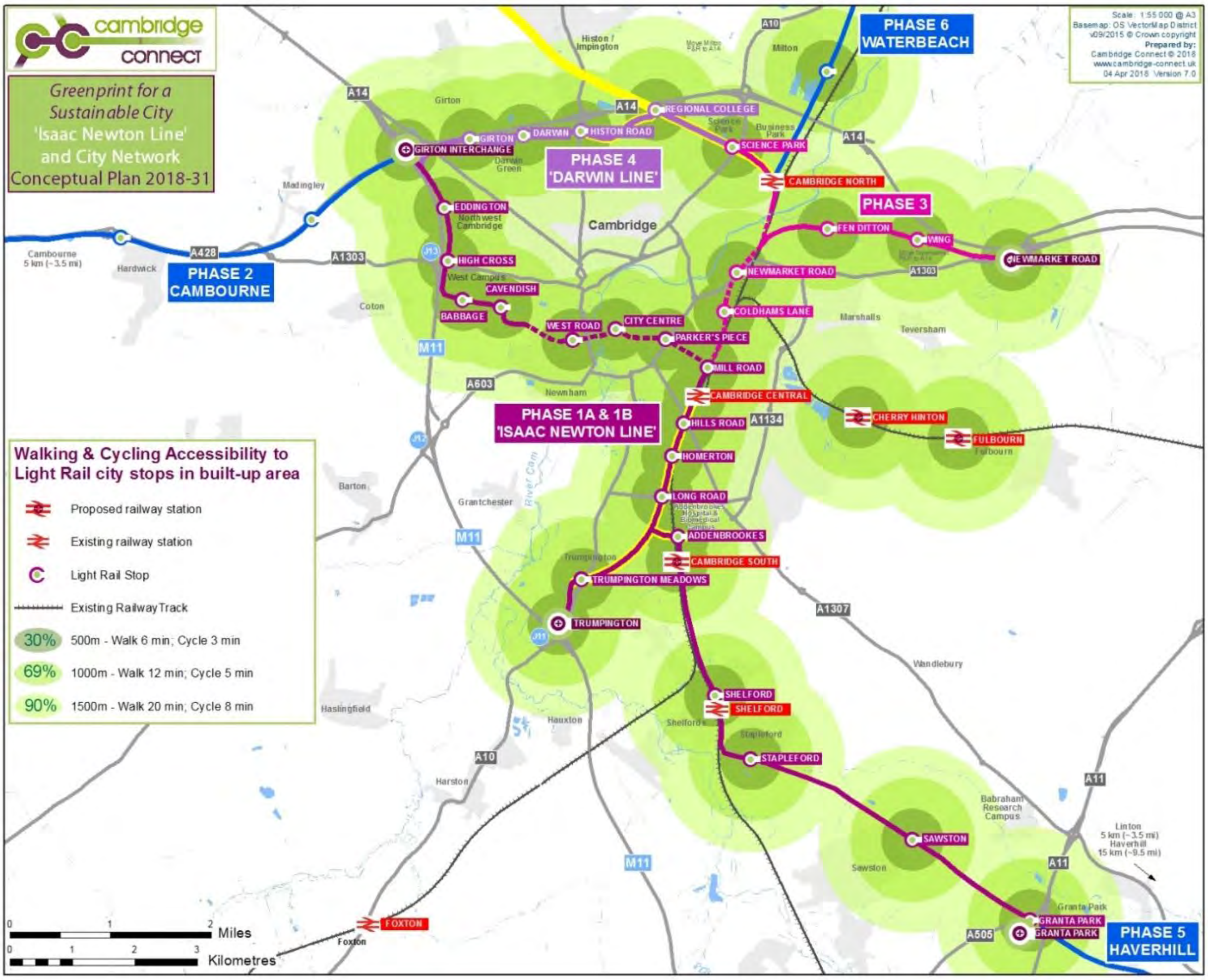

Figure 8 Accessibility of light rail network: distance and time to nearest stops in the city built-up area

The elderly, disabled and children

Modern trams are designed to be highly accessible for the elderly and the disabled, as well as for children. Low-level floors and wide doors enable easy access from the platform or street, making wheelchair and pushchair access especially efficient. Vehicles are child-friendly, with seating arrangements well-suited to families, and access easy and safe for parents with children through the wide doors. Space inside the vehicle is typically allocated for prams. This makes travel on light rail attractive and practical for the elderly, disabled and families with children, which broadens the overall appeal of public transport. Ease of access is an increasingly important consideration in the UK, as the population ages.

Inner City Parking

At present, particularly in weekends, hundreds of cars queue for long periods to access inner city car parks. This is time-consuming, inefficient, frustrating, and bad for the environment (air quality and carbon footprint). The 'queue to park' model accepted as normal in Cambridge is wasteful and unsustainable.

Cambridge Light Rail would make a dramatic improvement to the parking problems experienced in Cambridge by offering people a realistic and convenient alternative. By the size of the queues in weekends it is clear that buses are not offering an alternative that is sufficiently attractive for many (or do we British just love a good queue?!).

A rapid light rail alternative would be an attractive and convenient option that people would be likely to choose, and this would reduce congestion, reduce fuel wastage, reduce time wastage, improve air quality and be more sustainable.

5.4 Urban realm and city enhancement

Conservation and enhancement of the natural and built environment of Cambridge is a guiding principle for the public transport concepts presented in this report. This philosophy underpins a radical vision of an underground beneath the historic centre of Cambridge. This strategic choice is justified by the historical, cultural, and architectural importance of Cambridge and its standing as a city of global renown.

This approach is warranted to safeguard the qualities that make Cambridge unique and special. Cambridge is a centre of academic excellence, founded on a medieval core which today is of great historic significance. The University and College architecture and traditions are still very much a feature of this city, and together with the Backs and the Commons, a sense of tranquillity and proximity to nature still pervades.

However, in recent decades the city has been blighted by increasing traffic congestion and pollution, and growth of the population and tourism continue to place increasing pressures, paradoxically degrading the qualities of the city at a time of unprecedented economic and technological strength and success.

The historic centre

Over the last 25 years, the city has sought to resolve this tension between the conservation imperative and the needs of a thriving entrepreneurial culture through a development strategy in which major new research and employment hubs have been distributed around the periphery, with the historic centre in the eye of the 'storm'. This centrifugal pattern of development has largely succeeded in its primary objective, but the transport infrastructure required to interconnect it has not kept pace with the scale and speed of expansion. Cambridge Light Rail is designed to address this deficiency, both by maximising access and connectivity to the urban periphery in a sustainable way, at the same time as protecting – and enhancing – the traditional qualities and treasured spaces of the historic centre.

By placing the main mode of public transport into a tunnel beneath the city centre, we will ensure there is a quantum reduction in the environmental degradation to the urban realm that has arisen over recent years, and can only increase further unless a solution such as proposed by Cambridge Connect is implemented. This step will in itself be transformational for the historic centre, radically reducing the number of buses and coaches entering the core of the city, and greatly reducing other forms of traffic, and bringing the associated levels of congestion and air pollution down.

At the same time, placing major transport infrastructure underground frees up inner city space for initiatives to improve the urban realm, such as further pedestrianisation, while not compromising on the need to provide excellent access into the city centre for residents, businesses, educational institutions and visitors.

The urban periphery

At the urban periphery, a series of transport interchanges will mediate traffic flows between the sub-region and the city. Both new and existing facilities could become much more than simple Park & Rides, and there is an opportunity for bold and original master planning and architectural design.

These transport hubs have the potential to enhance the experience of visiting Cambridge if they are conceived as attractive, welcoming, efficient and sustainable gateways to the city. On the other hand, given the greater complexity of their new functions, a low-cost, low-priority approach to these edge-of-town locations could easily result in alienating environments reminiscent of some of England's larger and more depressing motorway service stations. Consequently, we suggest these sites require the same degree of planning and design attention and investment as the inner city stations.

By proposing the diversion of tourist coaches to new coach parks at the transport interchanges on the periphery, Cambridge Light Rail has the potential to act as a catalyst for rethinking of the city's approach to the tourism industry with the aim of improving both the tourists' experience of Cambridge and the city's experience of tourists. A well-managed and sustainable tourism industry will avert a potential future tourism crisis of the kind that has dogged major tourist destinations in Europe such as Barcelona. It could also increase revenue for the city while further enhancing our international image.

Suburban Cambridge

In contrast to the city centre, the lines running through suburban Cambridge will mostly be above ground. For the most part, these lines have been specifically designed to follow existing public transport corridors to minimise negative environmental impacts. In some places (for example, on the edge of Ditton Meadows where the alignment follows the former railway line to Burwell) special measures, such as additional landscaping and sensitive planting, will need to be considered to safeguard the built and natural environment.

Overall, however, the development of new light rail stations serving suburban neighbourhoods, many of which have historically been relatively deprived or neglected, will provide a catalyst for the kind of socio-economic and physical upgrading that new rail links typically bring, thereby reducing inequality between inner and outer Cambridge and fostering civic and community cohesion.

Indirect impacts of Cambridge Light Rail

In addition to the direct enhancements of the urban realm by Cambridge Light Rail, there are important indirect impacts to be exploited. A primary objective of Cambridge Connect is to substantially reduce traffic congestion within Cambridge by providing an attractive public transport alternative to the private car. Such a reduction will in turn facilitate the remodelling of areas of the inner city currently blighted by vehicular traffic. Many of these sites lie on or close to the inner ring road, including Mitcham's Corner, Elizabeth Way, East Road and Mill Road. These heavily-polluted and traffic-choked locations have the potential for radical transformation with the aim of restoring to them a sense of place.

The City Council has over the years conducted a number of studies in collaboration with local architectural practices to explore the potential for upgrading these areas and there is no shortage of good ideas on file. These studies highlight the enormous potential of sites like Mitcham's Corner, but the scope for change is currently constrained by heavy traffic flows. However, as a combination of positive public transport improvements like Cambridge Light Rail on the one hand, and perhaps judicious use of traffic restraint measures on the other, begin to take effect, a series of urban improvement projects could transpire to transform the inner ring road into a "necklace of pearls". At the same time, the strategic choice to prioritise a fully segregated light rail system over bus-based solutions, allows the road space thereby saved to be redeployed to facilitate cycling and walking and to reclaim urban space for people.

Placing transport infrastructure underground will dramatically improve our quality of life above-ground. Congestion and noise would be reduced, and inner city air quality would be improved. The number of buses operating in the city centre would be reduced.

Figure 9 Visitors and locals enjoy King's Parade on a summer's day. Photo: © Colin Harris 2009.

The Cambridge Coach Station could be relocated from the city centre to a site on the M11 at either the Girton Interchange or Hauxton / Trumpington Park & Ride site in the south. People travelling by coach could use the rapid light rail link to access the city centre, and the need for coaches to enter the city centre would be greatly reduced. This could offer significant advantages to coach operators as well, since they would no longer suffer the delays often experienced when accessing the city centre, particularly at peak times. This would enable more punctual timetabling and improve the profitability of coach companies.

Fewer buses and coaches would enhance the space within the City centre: by removing large vehicles, the urban space will feel more safe, open and pleasant. It could open up more opportunities, for example, to enhance spaces with pedestrian areas, street cafes, and so forth. The space for pedestrians and cyclists would be enhanced, and safer. Long-term, this would make the inner city a much more attractive place to visit, shop and to enjoy. That would be good for visitors and locals, and for inner city businesses.

5.5 Environment

Energy efficiency and carbon footprint

Around one third of energy consumption is used on transport (MacKay, 2009: 118). Rail remains the most energy-efficient means of public transport available, being at least twice as efficient as buses (including electric buses) and up to 18 times more efficient than cars. Improving the energy efficiency of our transport systems should be a key consideration in our transport decisions.

- London Underground electric trains have an energy cost of ~4.4 kWh/100p-km at peak times. This is 18 times better than cars with only one occupant, and around 1.4 times better than a full diesel coach travelling at full speed on a motorway.
- The London Underground operation as a whole on average delivers at an energy cost of 15 kWh/100p-km, which is more than twice as efficient as London buses at 32 kWh/100p-km (average), and more than five times more efficient than single occupant cars.
- A full 8-carriage train travelling at maximum speed of 100mph (161 km/h) consumes only 1.6 kWh/100p-km, not a lot more than the energy cost of riding a bicycle (~1 kWh/100p-km) but a lot faster!

The Aarhus Light Rail Project (Denmark) contributes annual energy savings of approximately 47 GW and reduces CO_2 emissions by 7300 t every year. While the Cambridge Light Rail network in the city would be more modest at ~36 km compared with the 110 km at Aarhus, the savings would nevertheless be substantial. If Cambridge were to achieve savings at the same rate, this would represent 15 GW of annual energy savings, and ~2336 t of CO_2 emissions every year.

LRV provider Alstom calculated that carbon dioxide emissions by light rail vehicles are around one third those of buses (35 g per passenger km (ppkm) compared to 100 g ppkm), less than a quarter the emissions of cars, and buses use 5 times more energy than trams (this latter claim seems at odds with McKay (2009) calculations noted above, so this may depend on vehicle details). Moreover, trams can move more than double the number of people than buses in an hour while occupying 15% less space.

Modern LRVs are very energy efficient and are able to provide far greater capacity across the network compared to buses. In terms of carbon footprint, if power is procured from green sources the carbon footprint is virtually zero.

This approach is consistent with commitments made at the 2015 Paris Summit on Climate Change, and in particular to adopt more sustainable approaches to city planning and transport. Transport infrastructure planners need to take these factors explicitly into account. A detailed analysis of the environmental benefits from a Cambridge Light Rail scheme should be undertaken.

Emissions, air quality and waste

Trams are 100% electrically powered, with no carbon, nitrous oxide or other pollutant emissions at the street, resulting in improved inner city air quality. Potentially, if the LRV power source is from a sustainable supply, trams have zero CO_2 emissions. Even if diesel buses employed today were replaced by electric, these typically hybrid vehicles still emit pollutants at the street.

All rubber-tyred vehicles generate black carbon pollutants (fine particulates) from tyre, road and brake wear. Emissions are higher from larger vehicles such as buses. Particulates are a significant source of pollution in our cities, and are hazardous to human health. Because LRVs run on rails, particulate emissions from this source are almost nil, resulting in significant health benefits for the population.

Non-exhaust particulates as a source of harmful air pollution need to be taken into account when comparing and making decisions about public transport options. Non-exhaust particulate emissions are of at least equal importance to tail-pipe particulate emissions. In addition, resuspension of particulates into the air is caused by vehicle movements. Such resuspension is exacerbated by rubber-tyred vehicles owing to the greater tyre-to-road interface.

In tunnels, additional ventilation is typically required to deal with the extra heat and fine particulate pollution generated by rubber-tyred vehicles when operated with metro frequency. Heat dissipation from braking is also an issue, usually addressed by regenerative braking. In addition, battery powered buses of equivalent capacity will be heavier than conventional vehicles, with consequent increases in generation of both particulates and heat.

Air pollution is a recognised and serious problem in urban environments, not least in Cambridge. Current pollution levels in Cambridge regularly exceed health guidelines. The costs of particulate emissions from rubber tyred vehicles, both in terms of impacts on human health and of additional investment required to mitigate pollution, need to be taken into account in modal selection of public transport.

Disposal of waste rubber tyres has implications for landfill and pollution costs, and this should be taken into account in modal selection. No waste rubber tyres are produced by light rail. Almost zero particulate pollution is generated by light rail. Regenerative braking is employed in light rail for energy recovery and the low level of particulate emissions is typically further minimized through magnetic technology.

Modal shift

It is important to offer public transport that is attractive enough to encourage people to switch from driving – but this is stubbornly difficult to change and in Cambridge bus patronage has remained steady at around 7-8% of commuters for more than 10 years. This overall percentage has not altered substantially despite the introduction of the Cambridge guided busway (data in Transport Strategy for Cambridge and South Cambridgeshire 2014). This low percentage using public transport is a poor achievement if one of our goals is to create a more sustainable city.

The evidence suggests that any alternative to travel by private car needs to be a real game-changer to motivate larger numbers of people to switch transport modes. Rapid, frequent and reliable transit systems such as light rail offer that possibility.

Ride quality of light rail is of higher quality than road, especially with a wider body and more spacious and comfortable environment. Many surveys have been carried out assessing tram versus bus travel and the results consistently show trams / light rail are preferred by the public, with a high percentage modal shift from car when compared with bus travel. These studies are influenced by the perception among the public that buses are slow and unpredictable, and improvements to bus services may address this perception to some degree. However, as the CGB example illustrates, improving the frequency and reliability of bus services, in themselves, are by no means guaranteed to achieve modal shift.

Moreover, buses are unable to compete in terms of energy efficiency and throughput to the city centre, nor in enabling cross-city journeys. History demonstrates they are not sufficiently attractive as an alternative to prompt the scale of modal shift both desired and required. Perhaps if the full scale of potential energy efficiency and environmental gains were costed and taken into account, light rail might compare favourably in overall cost against the alternative of buses, which are often claimed to be more affordable. Simple cost / benefit analyses that fail to take these factors into account are likely to misrepresent the true situation.

Light rail and tramways are generally higher cost per km to build and operate than buses. However, they are much more competitive when the cost per passenger km over a long time period is considered. The initial high cost dissipates over time, and light rail / trams become much more cost-efficient and cost-effective at the same time as driving modal shift.

Road maintenance

Large rubber-tyred vehicles impose significant loadings on roads, and road maintenance should be a major consideration in modal selection. Metro-style operating frequencies will exacerbate maintenance requirements significantly, potentially requiring special engineering solutions. Substantial repair and maintenance costs may arise due to 'tracking', as the extensive and costly repairs of the CGB illustrate. Moreover, the guided BRT network in Caen is being replaced by light rail because the heavy rubber-tyred guided buses caused the road surface to break up under repetitive stress loadings. When considering implementation of a public transport system that will run on roads (e.g. bus-based technology), it is essential to take into account those operational costs. Calculations should be made of additional loadings on routes and of the costs that will be incurred, and consideration needs to be given to who will be responsible for meeting these costs.

The impact of operational road maintenance on service reliability also needs to be taken into account, particularly within tunnels where we anticipate service frequencies will be at their maximum. This may cause disruption and impact significantly on reputation, which in turn may impact on the ability of the public transport network to deliver modal shift. These risks should not be ignored in modal selection, and the example of Caen illustrates how light rail can mitigate such difficulties.

Rails are specifically designed and employed to address these issues and remain the most efficient and effective solution to deal with the problem. While this elevates capital investment in construction, in whole-life terms operational savings make this investment cost-effective. There is a need to balance assessment of capital and operational costs when considering options, and whole-life costs need to be sufficiently considered in the analysis.

Sustainability

Sustainability (integrating technical, environmental, economic and social goals) should be central to decision-making. The performance of public transport options in terms of sustainability should be a key differentiating criterion guiding choice of the modal solution that is most appropriate for Cambridge.

The UN Sustainable Development Goals, agreed by all nations at a Summit in September 2015, include a specific target to expand public transport for the cities of the future over the next 15 years. The UK and Greece currently have the lowest length of light rail track in the EU at ~2.5 km per million inhabitants, which compares with Germany and Austria at ~38 km/, Belgium at ~30 km/, and the Netherlands at ~20 km/ per million inhabitants. The UK also has one of the lowest number of systems per million inhabitants in the EU (Table 3: Light rail and tram systems in Europe (2009) European Rail Research Advisory Council / UITP: p.25). These data show the UK has much room for improvement in the provision of sustainable and efficient public transport systems.

Modern light rail systems are relatively expensive to build initially, although present a significant advantage by being permanent, offering potentially at least 35 years of life with good maintenance practises. Light rail systems have the advantages of being able to carry large volumes of people in a high frequency service, meeting the capacity needs in city centres, areas of population and of workplace density. Their permanence also makes them predictable, enabling businesses and residents to make longer-term locational decisions with confidence in the public transport operation offering reliable service frequencies and run times. The same cannot be said of bus services, which are in decline.

Cambridge Light Rail would make a major contribution to improving the efficiency of the city and reducing the city's carbon footprint. Moreover, Cambridge Light Rail would encourage more people to cycle or walk on journeys for which they might otherwise take a car. In these senses, we regard public transport by light rail in Cambridge as a 'Greenprint for a Sustainable City'. These are urgent priorities, and given its prominence on the global stage for vision and innovation, Cambridge should be leading by example.

Figure 10 Sustainable transport policies protect our green spaces. Roman Road, Wandlebury. Photo: © C. Harris 2009

5.6 Education

University needs: 'Reality Checkpoint' has moved

Historically, the University of Cambridge was established within a compact city core, within a circle extending to what became known as 'Reality Checkpoint' on Parker's Piece. Within this confined space, interconnections were easy, and were further fostered by the College system. It is important that the components of the University of Cambridge remain well connected and integrated.

In recent years there has been increasing fragmentation of the University as developments have been focused – for sound practical reasons – at more widely distributed sites. Presently, these are poorly connected. For example, the West Campus is relatively isolated from many Colleges and departments, and yet increasingly is becoming an important focus of the University.

Modern cross-disciplinary research thrives on interaction, sharing of knowledge and ideas, and on the multitude of interconnections. This sometimes yields important, novel and unexpected advances. This is vital to keep the University and the Colleges at the cutting edge, and maintain its future leadership. It is essential, therefore, that spatial barriers to interaction are minimised, and that staff and students in the University are enabled to move rapidly, efficiently and sustainably between the widely distributed components of the modern University of Cambridge campus. This now includes the historic city centre, Addenbrookes BioMedical Campus and the West Campus. Moreover, the scope of interactions increasingly extends further afield, especially to London, Oxford, and to other universities and research centres – both government and commercial – throughout the UK and internationally. Good connectivity is vital to facilitate interaction.

Figure 11 University of Cambridge graduates at the Senate House. Photo: © Colin Harris 2011.

The 'Isaac Newton Line' would provide a very effective means of connecting staff and students across all three of the main components of the university. This would include links from the West Campus to University departments, Colleges and administration, to the Cambridge Central Rail Station for links to London and international airports, to Addenbrookes BioMedical campus and also to the Science Park, Babraham Research Campus and Granta Park, which would also help to improve commercial research links with the University. In addition, Anglia Ruskin University would be well connected at Parker's Piece.

Schools and Sixth Form Colleges

The Cambridge Light Rail network has been designed to support a number of schools and Sixth Form Colleges, in particular those located in the Hills Road, Long Road, Trumpington and Orchard Park areas. With an integrated light rail network extending across the city, and with stops accessible to residential areas as illustrated in Figure 8, access to these important educational facilities would be greatly enhanced.

6 Constraints

6.1 Inner city architecture and heritage

A major reason for proposing tunnels within Cambridge city centre is to protect the inner city architecture and heritage, including its important buildings but also open spaces of world renown such as The Backs and the various commons. This approach has been proposed cognisant of the substantial additional costs. However, this architectural and landscape heritage of Cambridge is globally iconic and of exceptionally high value, and the investment in an underground is the most responsible approach to addressing the pressing transport needs in the city while at the same time ensuring those values are protected for the long-term.

Tunnel engineering techniques are available to mitigate construction risks, such as subsidence, and these have been pioneered by Prof. Lord Robert Mair at the University of Cambridge. Most notable, the technique of compensation grouting that he developed has been successfully employed to protect iconic buildings such as Big Ben and the Houses of Parliament when the Westminster underground station was built as part of the Crossrail project. The technique is well proven, and is now adopted in tunnelling projects world-wide. These types of techniques would be employed to ensure that similarly iconic buildings in Cambridge would be adequately protected from risk. Moreover, careful routing of the underground line could avoid potentially sensitive structures, such as King's Chapel, should there be any concerns.

6.2 Archaeology

Of the routes and facilities indicated in the Cambridge Connect model (Figures 1 and 2), the single most crucial location for potential archaeological constraints is likely to be at the tunnel access at the proposed underground station in Cambridge city centre. The precise location of this station has yet to be determine, although it can be anticipated that approximately three metres depth of complicated urban-sequence strata can be anticipated in this locality, which would require significant excavation provision. The tunnel itself is anticipated to lie ~10 – 20 m below the surface, and below the level at which archaeological remains could be expected to be found, so the specific area of archaeological risk would be relatively limited.

Otherwise, there would be no specific 'hot-spots' along the network, and although archaeological remains could be encountered anywhere along the routes, all would probably be without horizontal stratigraphic survival (e.g. floor surfaces and, instead, just cut features). This means that all new (greenfield) route-, station- and portal-construction would require evaluation fieldwork beforehand (machine-dug trench-sampling), as is standard for these types of developments. It may be the case that, in some areas, such work has already occurred under the auspices of larger developments (e.g. University's West / North West Cambridge lands; Marshall's WING development east of the Newmarket Road Park & Ride). That said, depending on the actual construction specifics (e.g. depth and extent of disturbance), such evaluation fieldwork might also still be required where the routes follow old railway alignments. We would not anticipate that such work would be required on alignments where the CGB has been recently been built, since such investigations would probably have been undertaken at the time of this construction, although this would need to be verified.

As with any major development, should archaeological remains be discovered through the evaluation fieldwork, then those sites would require full excavation prior to construction.

7 Integration

7.1 Bus services

Bus transport is, and for the foreseeable future will likely remain, an important component in the mix of public transport provision in Cambridge. Buses can offer more flexible services than is possible on a fixed light rail line, and this offers advantages for deployment of public transport to a wide range of sites that would be impractical or too expensive by light rail. Buses are suited to routes where patronage is likely to be lower than served by light rail, and smaller sized mini-buses can be deployed to areas where demand is low.

Weighed against their advantages, buses are limited in capacity, are less energy efficient than light rail, and, where they do not have their own dedicated busways or buslanes, are subject to congestion delays just like any other traffic. In addition, these large vehicles are typically ~10-12 m in length by 2.5 m in width and weigh up to around 15 tonnes. As such, they require considerable surface space to operate and park, can block other traffic, and impose on other road users such as cyclists and pedestrians. These heavy vehicles with power steering stress inner city roads, increasing road maintenance costs. Rubber tyre wear and diesel produce black carbon emissions, which are harmful to human health. Buses are also less comfortable, with a typically bouncy ride.

Bus services should be improved where they offer real advantages, for example by enabling access to parts of the city and region relatively inaccessible to a Cambridge Light Rail network and, importantly, by connecting outlying 'satellite' towns, villages and employment centres beyond the present practical reach of a light rail network or heavy rail lines.

In the Cambridge Connect vision, buses would continue to play an important role by providing public transport links from outlying areas to nodes on the Cambridge Light Rail network (for example, the Park & Ride sites proposed at Girton Interchange, Wing / Newmarket Road (A14), Granta Park, and on the M11 near Trumpington), from which rapid access to the inner City and other important employment centres can be provided by light rail. This approach both connects the light rail network to the wider and dispersed regional community and provides the population with effective and efficient means to travel by public transport. The approach would also protect the inner city from environmentally destructive busways along surface radial roads to the city core.

Buses would also continue to play an important role in serving the needs of local people in parts of the city less accessible to the Cambridge Light Rail network. With Cambridge Light Rail meeting the needs of the majority of residents, needs for such local buses would diminish, and coupled with fewer buses and coaches entering the city from the wider region, overall pressures arising from bus congestion within the city core would be reduced. This would result in improvements to air quality, reduce congestion, and enhance the amenity of the inner city environment. With a Cambridge Light Rail system in place, 'Better Buses' is 'Fewer Buses' congesting the city centre.

7.2 Coach services

Inter-city coaches

The Cambridge Coach Station is co-located in the heart of the city near the Drummer Street Bus Station and Parker's Piece. Delivering passengers to the heart of the city is important for the convenience and needs of passengers, although coaches add to congestion already present in this area from local bus services. Additional taxis and private car traffic is generated to serve passengers, and needs to access the same restricted space. Even now, this arrangement is often severely congested, inefficient and inconvenient. Coupled with the space constraints of the central city bus / coach station, the routes providing coaches with access into the city centre are also often congested, which leads to delays and impacts the punctuality of coach services. The delays and uncertainties over punctuality act to further discourage people from taking public transport.

Cambridge Connect suggests that Cambridge Coach Station could be relocated from the city centre to the periphery should it be coupled with a connecting point on the rapid Cambridge Light Rail system. Coach passengers would switch onto light rail at the terminus, and the journey into the City from there would be only 10-12 mins (see Figure 7). The option to take the light rail could be included in the ticket at the time of purchase. Alternatively, coach passengers could take local bus public transport from the hub to local towns and villages, or they could be met by friends, family or a taxi should it be more convenient. Late at night, when light rail services may not be operating as fully, it would be practical for coaches to continue to access the inner city, although clearly at a time when few people are about and congestion is not an issue.

This approach offers benefits to passengers by enabling more reliable and more punctual journeys to the Coach Station, and rapid access from there to the City centre without the delays. It is acknowledged that a change in transport mode represents an inconvenience for coach passengers. However, there is a substantial benefit because passengers can then choose any of the other destination stops on the Cambridge Light Rail network (this would be at least 30 stops distributed around the city, and a further 10 regionally). This revolutionises passenger options**,** so they can easily get from the Cambridge Coach Station to stops close to their destination of choice. This in turn reduces, and spreads, the demand for taxis and private vehicles to pick up coach passengers, again substantially reducing pressures in the city centre, improving efficiency by eliminating and/or shortening pick-up journeys, and through this significantly reducing the carbon footprint and other environmental impacts. This represents a more sustainable approach to transport in the city and forms part of our 'Greenprint for a sustainable future' strategy.

Tourist coaches

The large number of tourist coaches entering the historic city core poses a considerable management problem. There is a need to deliver tourists close to sites of high interest, and yet these very sites are where space is at the greatest premium. The elderly or disabled may have a particular need for delivery close to sites of interest. Presently, these large coaches all need to travel into the City on busy arterial routes, then many will exit the City on these same routes to park up during the day, to return later to pick up their clients. This is an inefficient and cumbersome way in which to meet the needs of tourists arriving by coach. Enabling tourist coaches to drop passengers to the termini of the light rail network offers a potential solution to this problem.

Coach station locations

The Trumpington / Hauxton (J11) and Girton Interchange junctions are two possible candidate sites at which to relocate the Cambridge Coach Station, being situated as they are on the M11. The Girton Interchange offers some advantages because of its strategic position on the A14 and with potential linkage with the A428 west to Bedford and Oxford (once the current lack of interconnection is addressed). Travel time by light rail into the city centre from either terminus is similar at ~10-12 mins including stops. Consideration could also be given to locating coach stations at the other P&R sites with light rail termini.

7.3 Park & Ride

Existing sites

There are currently five Park & Ride facilities in Cambridge: Babraham, Newmarket, Milton, Madingley and Trumpington. These facilities provide parking so people can leave their cars and ride by bus into the City centre. The Cambridge Light Rail network would link to the same general locations as these five sites. Some adjustments are suggested to their locations in order to optimise points of connection to the light rail network and the wider region, and to better locate these facilities close to major highways (M11, A14, A10, A505 and A11 in particular) (see Table 9, Figures 1 and 2).

Proposals have already been published by the GCP and others to relocate the Newmarket and Trumpington Park & Rides, while a new Park & Ride has been proposed near the Madingley Mulch Roundabout near the junction of the A428 / A1303 or at Scotland Farm on the A428. Cambridge Connect supports a Park & Ride at the Girton Interchange rather than Madingley Mulch Roundabout or Scotland Farm because it would have superior connections on the M11 / A14 / A428 (assuming full connectivity at the junction is addressed). Moreover, travel to a Park & Ride at Girton Interchange on the A428 from the west and in particular Cambourne would be easily facilitated on this under-utilised section of 4-lane highway. This approach has a dual benefit of facilitating connections onto the M11 and A14 West from the A428, which would also alleviate current congestion down Madingley Rise (A1303) which occurs at morning peak hours by vehicles attempting to access the M11 South.

Granta Park is situated at a key strategic location on the A11 / A505, and is also close to the A1307 extending to Haverhill. A Park & Ride at this location could serve the important business cluster at Granta Park, and could also support nearby research campuses such as Babraham and Hinxton through the operation of frequent shuttles. In time, these shuttles are likely to be autonomous (trials are already in progress), and this would be an efficient way in which to link up all of these campuses into one dynamic 'research cluster'.

Table 9. Suggested Cambridge Park & Ride facility relocations

Name	Current location	Suggested location	Reason for move	Light Rail Stop
Newmarket	A1303	A14	Improve connection to A14. Avoid congestion along A1303.	'Wing'
Milton	A10 / A14	A10	Move to A10 at location of Waterbeach new town.	Waterbeach new town
Madingley	Madingley Road	Girton Interchange M11/A14/A428	Improve connection to towns in north and west. Superior strategic location to Madingley Mulch / Scotland Farm proposals by GCP.	Girton Interchange
Trumpington	Trumpington Road	M11	Improve connection to M11. Reduce congestion on Trumpington Road.	M11 Trumpington / Hauxton
Babraham	A1307 near Gog Magog Hill	Granta Park A11 / A505	The Babraham site would be redundant if a new P&R is established at Granta Park	Granta Park

New sites

Consideration should also be given to new Park & Ride facilities, locating these strategically so they can help facilitate travel to and from Cambridge by public transport from further out than is presently the case. Park & Ride facilities have traditionally been located close to City peripheries because this tends to engender greater patronage. However, this approach alone sends a clear message that people commuting from surrounding towns and villages are fully expected, indeed are *encouraged*, to drive by private vehicles to these points. The majority of these journeys will be made in single occupant vehicles, which are much less energy-efficient than public transport. This runs counter to the objectives of a more sustainable transport strategy for the region, and therefore the policy of locating Park & Rides solely around the periphery of Cambridge seems to warrant further careful consideration. For example, sites at Cambourne, Haverhill and Bar Hill could be considered. Such facilities could be designed at a range of sizes suited to the local context. By allowing parking spaces at stops along the length of the light rail network, this would encourage people to access the public transport network at a location that is close and convenient to them.

7.4 Automated vehicles and shuttles

In the future, we expect autonomous vehicles to play an increasing role in travel, although precisely when they will be in routine operation remains a matter for conjecture. Nonetheless, Cambridge Light Rail has been designed taking into account the probability that autonomous vehicles are likely to become an important form of transport within even the early stages of the scheme.

Owing to fundamental spatial constraints on the physical road space available, in particular within city centres, we take the view that a backbone of mass public transport will remain a necessary component in the mix of solutions that will make up future modes of travel. In order to move the required volumes of people into and out of the city on a daily basis, it seems improbable that this level of demand could be met by individual autonomous vehicles, each carrying a small number of persons. It is beyond the scope of our current study to attempt to model this system, although experience shows that this approach results in severe congestion by large numbers of vehicles attempting to access the city centre at the same time. Even if those vehicles are autonomous, or electric, the fundamental spatial constraint of the road space resource remains.

We therefore anticipate that a backbone of public transport provided by Cambridge Light Rail will play an increasingly important role in the future by providing that access to key destinations around the city and region while enabling people to avoid congestion. In this model, we envisage people will travel by private means (whether manual or autonomous vehicle, electric or otherwise, or by cycle or on foot) to the nearest point on the public transport network that is convenient, to then travel the longer distances on light rail to their destinations such as employment centres, educational facilities, shopping and entertainment centres, health facilities or to meet family and friends etc.

Automated vehicles could play an important role by providing shuttle services from suburbs, local villages or employment centres to nearby stops on the light rail network. For example, the Babraham and Hinxton research parks could be linked to the Park & Ride proposed at Granta Park in this manner.

7.5 Regional and national integration

Light Rail regional connections to Cambourne and Haverhill will support these growing centres and provide strategic access into Cambridge City from areas of lower-cost housing. Good light rail connections would unlock and support major development potential, and help to address the extreme strain on housing provision within the city of Cambridge. Good connections from Cambourne and Haverhill to centres of employment (e.g. West Campus, Biomedical Campus) will support employees that need to travel *and* support the businesses and organisations where they work. Light Rail connections would help to reduce commuter pressures on the road network by attracting people onto a sustainable alternative, thereby freeing up road capacity to meet commercial needs that cannot easily transfer to rail (e.g. trade and delivery services). Cumulatively, this will enable commercial operations to function more efficiently, and reduce the local pressures for road capacity expansion.

Phase 2 of Cambridge Light Rail to Cambourne is designed to support development needs identified in the new Local Plan. This would connect Cambourne and growing regional villages such as Hardwick, and Bourn, with the Isaac Newton Line at the Girton Interchange. In the southeast, Phase 5 of Cambridge Light Rail would link Granta Park to Linton and Haverhill via the former rail alignment.

A light rail line is proposed to serve the new town planned north of Waterbeach (Phase 6), which would extend from Cambridge North Station via Milton. This line potentially could include service to new housing proposed at the water treatment facility site near Cambridge North and the A14. As these housing developments are expected to evolve over a number of years, in the early stages and prior to Phase 6 development, the relocated Waterbeach heavy rail station could provide a service connecting the community to Cambridge North, Central and South rail stations, where access to the city light rail network would enable wide and easy connections across a wide area.

In early design consultations, Cambridge Connect considered a light rail option east to Cherry Hinton and Fulbourn, either parallel to, or sharing, the operational heavy rail line using 'Tram-Train' technology. The aim was to serve residents in Cherry Hinton and Fulbourn, and also the significant high tech employment hub where significant companies such as ARM, Syngenta, Illumina, and others are located. While 'Tram-Train' may be possible, it could introduce a number of complexities associated with mixing high-frequency commuter services with freight and passenger train services on this line to the east, and there could be capacity issues when East-West rail is fully developed. Balancing these considerations, as well as the level of investment that would be required, our current preferred option on this route is to establish two new stations on the heavy rail line, one at Cherry Hinton and one at Fulbourn. As this line is upgraded and East-West Rail services develop, we anticipate that trains could serve these stations approximately every 15 minutes, providing a practical and cost-effective solution that would also enable connections onto the light rail network at Cambridge Central and Cambridge South Stations.

Connections onto the national heavy rail network are vital for business, science, technology, universities, culture and communities. The national rail network plays an extremely important role in linking Cambridge to London and the wider UK, and to airports for international connections.

As such, the heavy rail network has been a key influence on the design of the Cambridge Light Rail network, with Cambridge Central Station placed at the heart of the Isaac Newton Line. Moreover, Phase 3 includes the Cambridge North station, which became operational in 2017. The Isaac Newton Line also recognises the likelihood of a third heavy rail station at Addenbrookes ('Cambridge South'). Much of the Isaac Newton Line from the Cambridge Central Station – Trumpington follows the current southern Guided Busway, which itself utilises the former Cambridge to Oxford rail alignment.

The Government and the National Infrastructure Commission have given support to developing the East – West Rail corridor linking Cambridge to Bedford, Milton Keynes and Oxford, and this has specifically been built into our strategy. The Cambridge Connect submission to the East-West Rail public consultation in March 2019 is available from our website.

Provision of public transport fit for purpose for Cambridge should be supported, provided the infrastructure is of high quality, and maintains and/or protects the area's environment and cultural assets (including the Green Belt). The East – West rail link coupled with the road 'Expressway' (e.g. dualled A428) will serve to stimulate further the Cambridge economy, making investment in the infrastructure needed for sustainable and effective public transport within Cambridge City of even higher priority. Should this fail to be recognised, many potential benefits of the East – West rail link will fail to be realised as the infrastructure within Cambridge City itself fails to cope. Cambridge Light Rail will be complementary to, and fully compatible with, East – West Rail by providing links at Cambridge Central, Cambridge North, and at the proposed Cambridge South stations. At this stage, it seems likely the general corridor for East – West Rail will run from Cambridge to Bedford via Sandy.

Cambridge has long been an economic centre for the region, and historically it has been a focus of local railways. Those railways have provided essential links to other centres of excellence throughout the UK, and to international travel hubs such as Heathrow and Stansted, fostering the innovation and dynamic entrepreneurship that is a hallmark of Cambridge and is of benefit to the overall national economy. Continued success depends critically on these links.

The travel-to-work area of Cambridge extends over a relatively wide area, and is focused around a number of distinct employment hubs throughout the Greater Cambridge area. Currently these hubs are often poorly interconnected within the city and with the railway station. The heavy rail network, in which major investments are being made in improvements, is playing a key role in serving the travel-to-work region and this can be further enhanced.

For example, Thameslink upgrades in 2018 will deliver four local trains per hour from the Royston line and more frequent and higher-capacity services to Ely and Kings Lynn. Trains will run from Cambridge through central and south London to Gatwick Airport, Brighton and Maidstone, as well as to Heathrow via Crossrail at Farringdon.. Frequent metro-like peak-hour services now transport two million passengers per year between Cambridge and Ely alone. More daily commuters use the railway rather than the parallel A10 road, and demand can be anticipated to continue to grow rapidly. As the East-West Rail project improves capacity between Cambridge and Newmarket, upgraded services on this line could soon work for the economy in a similar manner. These trends have significant implications for integration with the light rail network proposed by Cambridge Connect.

The links from Cambridge to London Liverpool Street and Stratford via Audley End will also soon deliver frequency improvements. Two trains per hour will operate throughout the day to Stansted Airport, together with improved services through the Cambridgeshire Fens to March, Wisbech, Whittlesey and Peterborough. Cumulatively, the major investments taking place across the heavy rail network in the Cambridge / London / Oxford triangle will provide Cambridge with a regional and national connectivity second to none. These developments need to be fully taken into account and leveraged to gain maximum benefits.

This network delivers over 12 million passengers a year to and from Cambridge station with some 35,000 to 40,000 passing through the station each day. The use of the regional network is increasing by 4.5% year on year and in less than ten years this throughput will be more than 70,000 per day. Without accompanying links directly into the city and linking to the employment centres of Cambridge, much of these benefits will not be fully realised. This is where light rail can play an extremely valuable and complementary role to the heavy rail network, providing the frequent and reliable essential local links that heavy rail is unable to provide on its own.

A Cambridge light rail network can integrate with the regional railway to enable the regionally dispersed workforce to travel with confidence on public transport to all the major centres of employment that are remote from the heavy rail stations. Currently most of these hubs are easily accessible only by car, with bus services providing a limited, unreliable and relatively unattractive service.

Investments in the railway, and more specifically light rail, send a tangible and powerful message to the marketplace that permanent commitment has been made to transport infrastructure in the region for the long term. This enables businesses and other institutions (e.g. education or medical services) to make locational decisions and investments based around that permanent infrastructure. This in turn enables motorists to shift modes with confidence, and make long term adjustments to their travel patterns oriented around a high quality public transport network.

In addition, employment centres more remote from Cambridge heavy rail stations will be connected in minutes, further enabling employees to use the heavy rail network to travel further afield, whether it is to home, for other work connections, to London or the airports. The phased delivery of the light rail network will facilitate and accelerate this process. Rail operators provide a dependable timetable as laid down in franchise commitments that is available for ~18 hours each day. By contrast, bus routes often fail to provide the long-term frequency, reliability and permanence in the same way, and many bus routes are withdrawn, often at short notice.

The combination of light rail and the regional railway network can provide an attractive alternative to road-based commuting, and this is proven in many cities where it has been implemented throughout the world. This is evident also in small to medium-sized cities most particularly in Europe, including cities similar in size to Cambridge. Moreover, Cambridge is growing rapidly, and it is surrounded by a relatively large regional population. The light rail and heavy rail networks envisaged in the Cambridge Connect will provide a well-integrated service that could unify disparate centres of employment in the Greater Cambridge area, stimulating the economy and enhancing access to employment and services and improving the quality of life.

Planned together as an integrated solution, regional rail and light rail can deliver public transport that is a true alternative to the car, driving the modal shift that is so badly needed. Together the network can deliver the future capacity required, and provide it with proven safety and confidence that will better enable long term investment decisions in this region.

7.6 Services integration: Smartcards and Apps

Smartcards and mobile phone apps are expected to play an increasing and key role in facilitating travel on the transport networks. These technologies can enable convenient and seamless access between network components, greatly simplifying ticketing and access. In addition, these technologies can reduce the friction of interchange by providing integrated tickets across modes and network sections. We anticipate this technology will help enable integration between light rail, heavy rail and bus services, and this will further stimulate use of public transport.

For example, passengers travelling to Cambridge by heavy rail could include light rail access within their electronic ticket, making mode change easy and more seamless. This facility has long been available in London, with train tickets optionally including tube and bus access. This approach is already widely adopted in many cities throughout the world, and should be introduced to Cambridge.

8 Phasing

Delivery of Cambridge Light Rail will necessarily need to be phased, and priorities for scheme implementation should be guided by a number of principles such as the need to:

1. Serve corridors and loci with high demand potential such as sites with high employment, commercial activity and / or population base;
2. Deliver early phases within a reasonable time-scale in order to commence revenue generation as soon as practicable;
3. Deliver scheme elements with relatively few technical and planning barriers to implementation;
4. Deliver scheme elements where there is a strong economic, business and planning case;
5. Deliver a high-quality and superior service from the outset, generating positive feedback to reinforce scheme development in further phases.

The overall Cambridge Light Rail scheme, which is a long-term vision, has therefore been segmented into a number of practical, deliverable phases based on these principles. The general priority, timing and costs of these phases are set out in Table 10 below.

Table 10. Cambridge Light Rail: delivery by phase, alignments, timing and estimated cost

Phase	Name	Route alignment	Features	Length (km)	Time (~mins)	Timing	Cost (£m)	Cost with 40% OB (£m)
1A	Isaac Newton Line	Cambridge Central Rail Station to Trumpington (M11), Addenbrookes, Sawston, Granta Park.	Southern busway conversion, incl Maintenance Depot (~£40m).	14.4	17.5	2018 – 2022	407	569
1B	Isaac Newton Line	Cambridge Central Rail Station to City Centre, West Campus and Girton Interchange	Bi-directional tunnel from near rail station to near Cavendish Labs.	7.7	14	2018 – 2024	550	770
Isaac Newton Line total				**22**	**31**	**2024**	**957**	**1339**
2		Girton Interchange to Cambourne	Surface. Follows A428 general alignment.	10.6	10.6	2022 – 2024	272	380
3		Cambridge Central Rail Station to Cambridge North, Science Park and Wing	Bi-directional tunnel from near rail station to near Cambridge North.	8.3	15	2022 – 2025	445	623
4	Darwin Line	Science Park to Eddington / West Campus	Surface, follows A14 general alignment.	5.5	10	2024 – 2026	145	203
5		Granta Park to Haverhill	Surface, follows general alignment of former rail line.	15.3	15.3	2024 – 2026	386	540
6		Cambridge North to Waterbeach via Milton	Surface, follows general alignment of rail line. Potential to serve housing and recreation park in NE.	7.6	7.6	2027 – 2028	195	272
7		Cambourne to St Neots, Wyboston		12.2	12.2	2028 – 2030	308	431
City and Regional Network total				**81.5**		**2030**	**2728**	**3788**
…		St Ives to Huntingdon	Northern busway conversion			2030 –		
…		Wing / Newmarket Road P&R to Burwell via Bottisham		10.8	10.8	2030 –		

9 Cost

9.1 Phase 1A / 1B 'Isaac Newton Line' cost

A preliminary estimate of the cost of the 'Isaac Newton Line' is £957 m (Table 11). This estimate is based on an ~£25 m /km for light rail line development (assumed £12.5 m /km in tunnel, because tunnel provides the alignment). We note that the 49 km Borders Railway in Scotland was completed in 2015 for a total cost of £353 m, equating to £7.2 m /km. Other estimates suggest ~£23 m /km for extensions to Nottingham NET. Thus, the estimate made of £25 m /km is considered reasonable for current purposes, and caution is needed when highly inflated per km costs for rail are quoted, as can be the case. For tunnel construction we have used the estimate given by London Bridge Associates of £54 m /km for a bi-directional tunnel suited to standard light rail vehicle (Steer Davies Gleave 2018). To these estimates we have added 40% Optimism Bias (OB). Station costs will vary widely, depending on location, type and whether the station is underground. Many stations could comprise structures as simple as large bus shelters, and their costs would be insubstantial. Full underground platforms, however, will be much more expensive, and these have been estimated at ~£50 m each plus 40% OB.

Table 11 summarises the estimated costs for the 'Isaac Newton Line', including tunnelling, stations, rolling stock (16 trams to provide a 5 minute headway) and an initial maintenance yard / depot. The tunnel and underground stations account for ~40% of the costs on the 'Isaac Newton Line', and is a major proportion of the overall costs of the scheme. However, we consider that the outstanding heritage and landscape values of Cambridge more than warrant a long-term investment of this magnitude, which will prove of enduring and great benefit for current and future generations. Attention should however be focused on how these costs can be kept as low as possible while at the same time maintaining a high-quality solution. For example, costs can be reduced by keeping tunnel length and diameter to the minimum necessary, and by reducing the number of underground stations. It may be possible to finance tunnelling by a special mechanism, to keep these costs off balance sheet, and this possibility should be examined.

By comparison, the cost of the light rail network established in Nottingham was ~£850 m, while the upgrade to the A14 highway is projected to cost at least £1500 m (Highways England 2016). The investments proposed for the 'Isaac Newton Line' are comparable, and we consider are justified in the Cambridge context.

Table 11. Estimated cost of Phase 1A / 1B 'Isaac Newton Line'.

Component	No.	Unit Cost £M	Total £M	Total with 40% OB
Light rail line (km)	22	25 (12.5 in tunnel)	511	715
Tunnelling (km)	3.2	54	173	242
Stations (underground)	4	50	200	280
Stations (above ground)	14	0.25	5	7
Rolling stock etc	16	3	48	67
Rail yard / Maintenance Depot	1	20	20	28
Total			**957**	**1339**

Phase 1A (~14 km) runs overground between Cambridge Central Rail Station, Addenbrookes and Granta Park and includes the spur to Trumpington / Hauxton M11. This section could be delivered for a cost of ~£407 m (£569 m with 40% Optimism Bias) and also relatively quickly.

9.2 Phase 2 Cambourne costs

Phase 2 involves construction of ~10.5 km of overground light rail line from the Girton Interchange to Cambourne, roughly following the alignment of the A428. We estimate the cost of Phase 2 to be ~£380 m including rolling stock, stations and OB.

9.3 Phase 3 Cambridge Central Rail Station to Wing costs

Phase 3 involves construction of 2.9 km of underground line and ~5.4 km of overground line from the Cambridge Central rail station to Cambridge North station and the Wing development in the NE. We estimate the cost of Phase 3 to be ~£623 m including rolling stock, stations and OB. Again, a large proportion of these costs are attributable to the tunnelling and two underground stations.

9.4 Phase 4 Science Park to Eddington costs

Phase 4 links the Science Park to Eddington and the Girton Interchange, serving northern side of the city and villages. It involves construction of ~5.5 km of overground line. We estimate the cost of Phase 4 to be ~£203 m including rolling stock, stations and OB.

9.5 Phase 5 Haverhill costs

Phase 3 involves construction of 15.3 km overground line from Granta Park to Haverhill. We estimate the cost of Phase 5 to be ~£540 m including rolling stock, stations and OB. The relatively high cost is driven by the distance.

9.6 Phase 6 Waterbeach costs

Phase 6 would link Cambridge North station to Milton and Waterbeach by 7.6 km of overground. We estimate the cost of Phase 6 to be ~£272 m including rolling stock, stations and OB.

9.7 Phase 7 St Neots costs

Phase 7 involves construction of 12.2 km overground line from Cambourne to St Neots. We estimate the cost of Phase 7 to be ~£431 m including rolling stock, stations and OB.

9.8 Future Phases

We have not estimated the costs of future Phases, although potential exists for further enhancement to the network, for example by extending to Burwell and Bar Hill. These options would enhance the overall network, although in view of the fact that a full programme of development is indicated for around ten years, we would suggest these options are better developed in future discussions.

10 Investment

10.1 Affordability

The illustrative affordability scenario in Table 12 considers the implementation of the 'Isaac Newton Line', Phase 2 (Cambourne) and Phase 3 (Wing) by 2025 (seven years). Based on the figures above, which include an Optimism Bias of 40% on top of the costs considered realistic, it would be achievable for Cambridge Light Rail broadly to break even after capital repayments on loans. The scenario is indicative, and we recognise that more detailed work is needed on the economic and business case.

By adopting a phased approach, we suggest that implementation of a high quality, proven and highly attractive light rail scheme is practical and deliverable within reasonable time-frames, and it would also be affordable if approached with the right mix of financial mechanisms.

We recognise however that the scheme is ambitious and that some of the major investment required is front-loaded onto the early stages of the scheme – in particular the tunnel and underground stations on the 'Isaac Newton Line'. While this represents a significant challenge, we take the view that the investment would be both responsible and enduring in the Cambridge context, and given the scale and pace of the pressures upon us this approach is more than warranted. We take the view that national-level support is justified in this particular case, taking into account all the factors related to importance of the Cambridge economy to the United Kingdom, its unique and outstanding heritage, and the extraordinary levels of growth that the region is experiencing.

Phased over 12 years, there would be an average annual cost of £316 m per year to deliver the entire scheme of Phases 1 to 7, assuming the overall cost of £3.79 bn (which includes 40% Optimism Bias).

Table 12. Hypothetical affordability for supporting Phases 1 to 3 of Cambridge Light Rail by 2025.

Expenditure	**£m**	**Income**	**£m**
Phase 1A / 1B 'Isaac Newton Line'	Inc OB 40%	City Deal funding	350
Light rail line	715	Devolution funding	400
Tunnelling	242	Government grant for tunnel	400
Stations (underground)	287	Developer contributions	100
Rolling stock	67	Institutional investments - 10 @ £10m	100
Rail yard / maintenance depot	28	Subtotal	1350
Subtotal	1339	**Borrowed income**	
		Bond issue	400
Phase 2 Cambourne	380	Land value uplift	500
Phase 3 Wing	623	Banks	92
Seven year expenditure 2018 -2025	2342	*Subtotal*	992
		Seven year income 2018 - 2025	2342
Phase 4 Science Park - Eddington	203		
Phase 5 Haverhill	540	Operating income 2025	
Phase 6 Waterbeach	272	Commuter - 5% commuters 4m journeys @ £2.00	8.0
Phase 7 St Neots	431	Non-commuter - 2.5% journeys 5.6m journeys @ £2.00	11.2
Total expenditure to 2025 - 2031	1446	Tourist - 10m journeys x 25% x £4 fare	7.8
		Income on land value uplift	30
Operating costs		Work-place parking levy	8
(Nottingham NET comparison)	10	Merchandising	0.5
Nottingham NET x "Cambridge factor" annual ops	15	Total operating income	66
Service Interest on loans			
Borrowed income @3% annual	30	Annual Surplus income over expenditure	20.7
Total operating costs	45		
Capital repayment on loans			
£1042 m repaid over 50 years	19.8	Annual Surplus after capital repayments	0.9

11 Conclusion

Light rail has the potential to help address transport needs in our region and have a transformative effect on our economy, life-styles and environment. It is affordable when considered in a phased approach with investments paid for over a period of 10-20 years or more. The benefits accrue across all aspects of life in Cambridge, and include travel speed, reliability, efficiency, convenience, comfort, and improvements to the environment and our quality of life.

Light Rail is a practical and important potential solution to Cambridge transport challenges, and is adopted in hundreds of cities world-wide. While more expensive in the near term, it should be considered seriously as part of integrated and enduring solutions. Light Rail offers the speed, capacity, frequency, reliability, convenience and accessibility to bring about the major improvements needed in the connectivity and efficiency of the Cambridge transport network. Light Rail is also highly scalable, to take account of growing future demand. It is the proven technology most likely to enable the substantial change in people’s journey decisions that is needed to create a more sustainable city.

The Cambridgeshire-Peterborough Combined Authority has responsibility for strategic planning of transport in the region, and is showing a far-sighted and progressive approach, including in its support for development of a mass transit solution for the region. We are encouraged that in 2017 the Greater Cambridge Partnership (which oversees delivery of the City Deal) has shown a longer-term approach. Both organisations commissioned a high level appraisal of strategic mass transit options, including light rail (Steer Davies Gleave 2018). The principal conclusions were that a mass transit solution is needed, and that a network model very similar to that proposed by Cambridge Connect should be adopted, including with tunnels in the city centre. These conclusions were reaffirmed in the Strategic Outline Business Case for the Cambridgeshire Autonomous Metro (CAM), published in March 2019 (Steer 2019). Cambridge Connect strongly supports this more far-sighted approach for an integrated and sustainable transport strategy for the Cambridge region, although we would like to see more and stronger evidence in support of the rubber-tyred articulated bus that is proposed as the mode to operate on the CAM.

Cambridge Connect has developed conceptual plans for a Cambridge Light Rail system. The first priority in the network we call the 'Isaac Newton Line', referencing the innovative approaches that are a hallmark of Cambridge. The network would be developed in a phased manner, with delivery of the core components by 2025, and additional phases being developed through to 2030. Much detailed technical work remains to be done, although Cambridge Connect believes that the evidence currently shows this approach would be an enduring and sustainable solution fit for purpose for Cambridge in the 21st Century.

The scale of investment needed is challenging, of that there is no doubt. However, by phasing delivery we suggest that this can be both affordable and deliverable. By selecting light rail as the mode of choice – a well-established and proven technology that is reliably deliverable and yet being enhanced by new innovations all the time – the responsible authorities can rely on a proven solution that will minimise their exposure to risk.

In the first instance, the ‘Isaac Newton Line’ (Phases 1A & 1B) would cost in the order of £957 m to deliver (£1.3 bn with 40% Optimism Bias), and this would meet many of the core needs in Cambridge city. Extending 22 km from the Girton Interchange to Granta Park, with a short tunnel in the city centre, the ‘Isaac Newton Line’ would link together all of the campuses of the University of Cambridge, link the central city to the Addenbrookes Hospital area, integrate with major employment and technology clusters, and link closely with the regional and national heavy rail network.

The surface component of the 'Isaac Newton Line' (Phase 1A (~14 km) between Cambridge Central Rail Station, Addenbrookes and Granta Park and including the spur to Trumpington / Hauxton M11), could be delivered for a cost of ~£407 m (£569 m with 40% Optimism Bias), and also delivered more quickly because conversion of the southern busway should be straightforward in terms of planning requirements, and dealing with services / engineering etc. because much of the alignment already exists.

Over the 12-year strategic delivery period for Cambridge Light Rail – which would see delivery in seven phases to includes light rail lines to Cambourne and St Neots, Haverhill, Waterbeach and connect Eddington to the Science Park – the overall cost for the scheme would be £2.73 bn (£3.8 bn including a 40% Optimism Bias). This equates to an annual investment of £227 m annually (£316 m including 40% Optimism Bias) over the twelve-year strategic delivery period.

Delivery of a very high quality light rail scheme that would meet the needs of economic development, protect the important heritage and landscape values of Cambridge, enhance our quality of life and social connectivity, drive modal shift, and support a more sustainable approach to transport in the region, for the annual cost of £277 m (or £316 m with Optimism Bias) for twelve years should be considered a very wise investment.

This approach would be transformational and highly positive for the region. It would support economic growth and the much-needed housing delivery, meet both business and University needs, would help protect the environment and reduce pollution, would be highly valued by both current and future generations, and represents a 'Greenprint for a Sustainable Future'.

Figure 12 Light rail / tram with cyclists in Amsterdam. Photo: C. Harris 2017.

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Figure 13 More sustainable approaches are needed in Cambridge. Photo C. Harris 2017

13 Appendix One – Authorship

This report has been prepared by a small team representing Cambridge Connect, Railfuture and UK Tram as follows:

Dr Colin Harris, PIEMA – Lead Author / coordinator

Dr Colin Harris is Director of the planning, mapping and publishing consultancy Environmental Research & Assessment, based in Cambridge. Dr Harris gained his PhD in Geography with a specialism in environmental management and spatial planning from the University of Cambridge, and has worked in this field for 25 years. He is a Practitioner in the Institute of Environmental Management and Assessment. His principal professional focus is on environment, sustainability and strategic spatial planning.

Colin initiated *Cambridge Connect* to promote sustainable and enduring approaches to address Cambridge transport challenges, in particular light rail with an underground component in the historic city core. Colin has worked with local and regional organisations to analyse the transport problems and to examine alternatives to address the issues, including light rail, and has published and presented widely on the subject. He has played a leading role in placing an integrated public transport network, light rail and an underground for Cambridge onto the agenda for consideration by local authorities.

Ian Brown CBE FCILT

In a career spanning over 40 years, Ian Brown has made an outstanding contribution to public transport and the rail industry. His extensive achievements include playing a leading role in establishment of the Docklands Light Railway and the London Overground, the major extension of the East London Line, the integration of Croydon Tramlink into TfL and the expansion of Oyster pay as you go to all National Rail stations in Greater London. Highlights of Ian's career include the British Rail Policy Unit, Managing Director of Railfreight Distribution, policy adviser to SNCF, and Chief Passenger Manager at the London Midland region.

Ian retired as Managing Director of TfL's London Rail in 2011 after 10 years in the role, and was honoured with a CBE in the 2011 New Year Honours list for services to the railway industry.

Ian was appointed a Vice President of Railfuture in May 2012. In May 2014 Ian was elected to the National Board of Directors of Railfuture and has held the role of Director of Policy since then. He has been instrumental in determining Railfuture's policies at a strategic level and has written several of its submissions to the Department for Transport. Ian is also a Board Member of UK Tram.

Peter Cushing

Peter Cushing was until recently Director of Manchester Metrolink, with responsibility for the day to day operation and delivery of a £1.8bn capital programme, retiring in 2017. He has extensive operating experience at board level, underpinned by business development and commercial expertise gained throughout a successful and progressive career within the logistics, rail and consultancy / interim management sectors. Peter has significant experience working with senior local and central government bodies delivering major capital programmes in the UK and overseas in addition to holding full P&L responsibility whilst leading the evolution and development of effective change in a variety of large, complex operational environments.

Peter has provided leadership in migration / transition planning, merger planning and organisation design in a variety of Light Rail Transit and Metro assignments in the UK and abroad. He has been a senior figure in other consultancy projects including operations and commercial analysis roles for DfT, and several major rail bids.

Peter Wakefield

Peter Wakefield was chair of Railfuture East Anglia until 2017, a role he held for over 20 years. In this role he advocated for public transport improvements, recognising the crucial link between a quality railway and sustainable economic development. For example, Peter led the Railfuture campaign to restore East – West links between Cambridge and Oxford, and through sustained effort this initiative is now coming to fruition. He was active in the successful campaign to establish a new station at Cambridge North. Peter has practical knowledge of the rail industry, as well as of the UK rail network and operations. Peter is interested in helping decision makers to make prudent forward-looking plans for the rail network and public transport services, which he sees as vital for our quality of life. Peter played an active role on the Rail Freight committee of Railfuture, has contributed to numerous Railfuture submissions to government and in consultations, and has been a spokesperson on topical issues. Peter has played the lead role in the Cambridge Connect initiative for Railfuture.

Paul Hollinghurst

Paul Hollinghurst is Secretary of Railfuture East Anglia, and has played an active role in a number of transport projects, including assessing and reporting on the feasibility studies and business cases relating to reinstatement of railways to Wisbech and Haverhill. Paul has written analysis reports for Railfuture on topical issues, and has been a regular contributor to Rail East. He is a resident of Cambridge with first hand local knowledge and extensive personal experience of public transport services.