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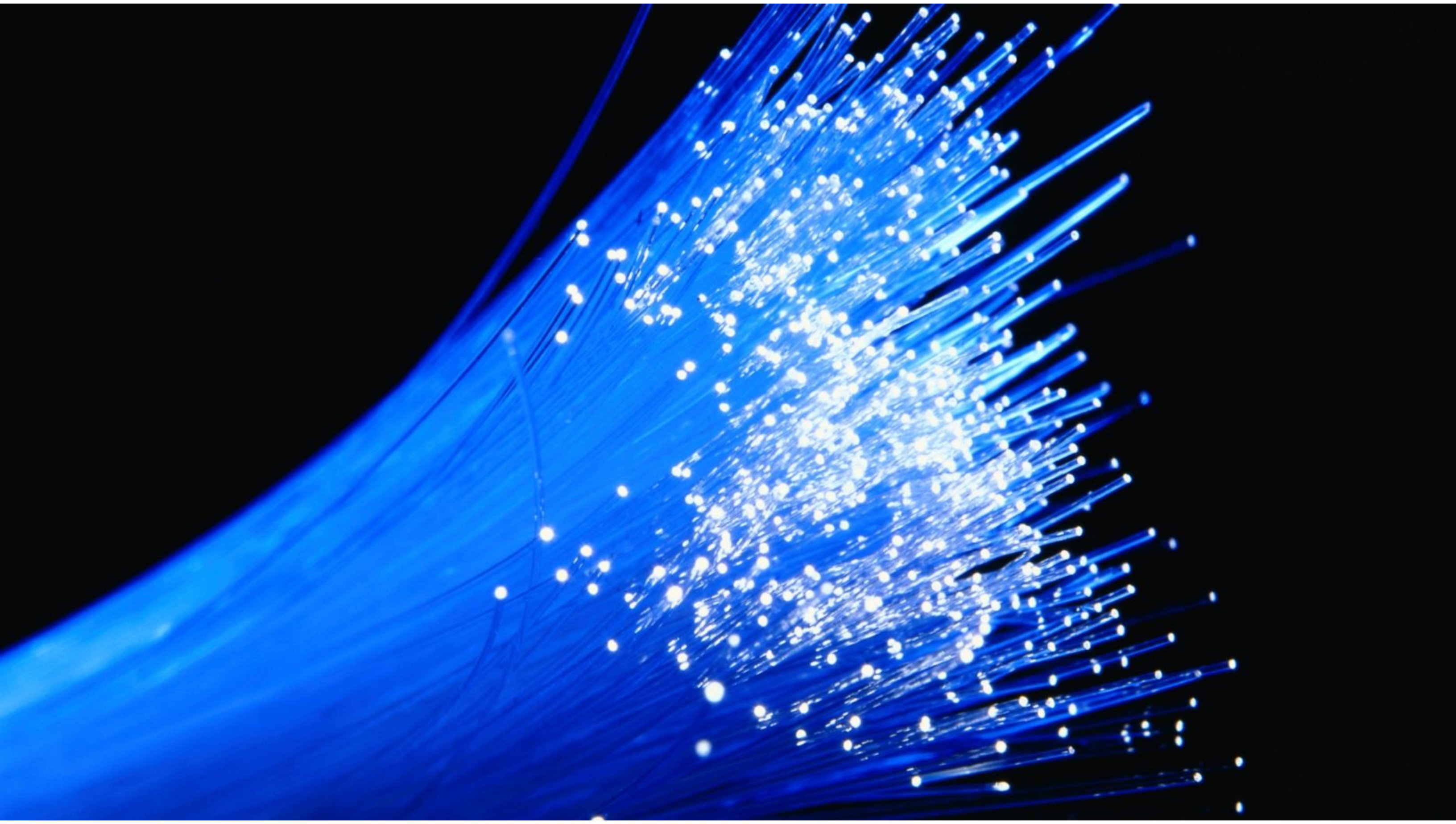

Municipal Broadband in Cambridge: Feasibility and Business Model Options

Prepared for the City of Cambridge, Massachusetts

March 2023

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1 Executive summary

This report examines the feasibility of the City of Cambridge implementing a municipal fiber-to-the-premises (FTTP) service and finds that for the City to construct an FTTP network and establish a financially sustainable business—meaning one that covers its costs and generates a reasonable rate of return over a long period—a significant public contribution would be required.

In a base-case scenario that applies conservative construction cost assumptions and reasonable revenue projections, the network could require an upfront public capital contribution of $150 million. This is not the cost of the network (described below), but rather the amount of the investment the City would need to make—with no expectation of a financial return—given the estimated construction and operating costs, less anticipated revenues.

But "municipal broadband" does not mean the City must be the only entity that builds, operates, maintains, and directly markets and offers retail services. Successful models of city-owned FTTP networks include those in which a city enters into an agreement with one or more private partners. As such, this report describes models for the City to deploy municipal broadband with varying degrees of private partner involvement. In a partnership scenario—following a potential future procurement effort—the City might find a partner able to bring operational economies of scale or existing assets to the table; these could lessen the magnitude of any required City contribution.

There exists a strong likelihood of private interest in a partnership with the City on a broadband network, particularly given the relative lack of competition in Cambridge. Even though high-speed competition does exist in some parts of the City, Comcast dominates the Cambridge market—holding an 80 percent market share, according to the survey conducted for this study. Across the nation, fiber providers are increasingly entering markets in which most households have only one choice for high-speed wired service—typically from the local cable company, as in Cambridge. The survey conducted for this study also demonstrates significant public support for the City taking steps to bring about a new FTTP service, even if a public contribution is required.

This report, prepared by CTC Technology & Energy and Rebel Group, outlines the options, opportunities, benefits, and risks for different business and partnership models; makes certain recommendations about the partnership approaches; and describes next steps for pursuing these approaches if the City is interested in doing so.

The following sections summarize the key findings.

1.1 Constructing an FTTP network to reach all 52,300 residences and businesses in Cambridge would cost an estimated $124 million to $161 million in 2022 dollars or $149 million to $194 million when considering inflation

An FTTP distribution network reaching all 52,300 residences and businesses in Cambridge, including all 33,000 apartments or condos in multi-dwelling units (MDU), would cost an estimated $124 million to $161 million in 2022 dollars. The higher number adds a 30 percent contingency. The project team added an inflation factor to arrive at a nominal (i.e., year-of-expenditure) cost of $149 million to $194 million, which reflects capital costs including inflation over a five-year construction period—as discussed in the next section.

This estimate assumes 62 percent aerial construction using existing utility poles, and 38 percent underground construction—as well as a 40 percent take-rate (that is, the percentage households or businesses choosing to take service). It is necessary to choose a take-rate to develop a capital cost estimate because capital costs include installing connections from the street to the premises and activating service; the total figure therefore varies by the number of subscribers. If a 100 percent take-rate is used—which would apply in the event the City built connections to all potential subscribers regardless of whether the household or business subscribes—the estimated cost ranges from $153 million to $199 million in 2022 dollars, or $188 million to $244 million using inflation-adjusted dollar figures.

Table 1 provides these cost estimates and components. Section 3 provides a detailed explanation of the costs and methodologies used to produce these estimates. These methods included field surveys performed by senior telecommunications outside plant engineers on all streets in Cambridge to collect data on pole conditions and other construction conditions.

Table 1: Estimated cost to construct a citywide FTTP network in 2022 and nominal dollars (that is, dollars in the year of expenditure, including inflation)

Cost attribute	Estimated costs @ 40% take-rate		Estimated costs @ 100% take-rate	
	2022 dollars	Nominal dollars	2022 dollars	Nominal dollars
Project management & engineering	$15.6M	$18.4M	$15.6M	$18.4M
Utility pole make-ready	$4.1M	$4.8M	$4.1M	$4.8M
Aerial strand construction (labor & materials)	$1.6M	$1.9M	$1.6M	$1.9M
Conduit infrastructure construction (labor & materials)	$34.3M	$40.5M	$34.3M	$40.5M
Fiber optic cables and components	$4.1M	$4.8M	$4.1M	$4.8M
Fiber splicing, testing & documentation	$1.1M	$1.3M	$1.1M	$1.3M

Cost attribute	Estimated costs @ 40% take-rate		Estimated costs @ 100% take-rate	
	2022 dollars	Nominal dollars	2022 dollars	Nominal dollars
Hub facilities	$1.0M	$1.2M	$1.0M	$1.2M
MDU laterals and cabling	$23.2M	$27.4M	$23.2M	$27.4M
City construction oversight & police detail	$11.5M	$13.6M	$11.5M	$13.6M
Core network electronics	$7.9M	$8.8M	$7.9M	$8.8M
Total fixed cost	**$104.3M**	**$122.6M**	**$104.3M**	**$122.6M**
Fixed cost per passing	$1,994	$2,345	$1,994	$2,345
Distribution electronics cost	$4.2M	$5.6M	$10.3M	$13.7M
Customer activation cost *(includes service drops & customer premises equipment or CPE)*	$15.5M	$20.6M	$38.7M	$51.6M
Total cost (without contingency)	**$123.9M**	**$148.9M**	**$153.2M**	**$187.9M**
Total cost per customer	$5,923	$7,117	$2,929	$3,594
Contingency (30%)	$37.2M	**$44.7M**	**$46.0M**	**$56.4M**
Total cost (with contingency)	**$161.1M**	**$193.5M**	**$199.1M**	**$244.3M**
Total cost per customer	$7,700	$9,252	$3,807	$4,672

1.2 A citywide FTTP network would likely require a significant upfront capital contribution to be financially feasible

For the City to establish a financially feasible FTTP business—meaning one that covers its costs and generates a reasonable rate of return over a long period—a significant upfront capital contribution by the City would be required.

Determining feasibility involves evaluating numerous variables including capital cost, ongoing operating costs, take-rate, pricing, project term, and interest rates. Section 4 provides a detailed discussion of these factors, describes the financial model built to evaluate the impact of these variables, and analyzes various combinations of inputs to determine the required contribution level under different scenarios. Given the uncertainty underlying each of the inputs, the resulting upfront contribution amounts should be considered order-of-magnitude estimates, which can be used to help understand relative differences between scenarios.

1.2.1 The project would require a $150 million upfront contribution using relatively conservative assumptions, including that 40 percent of premises subscribe

If the project achieves a take-rate of around 40 percent (which has been met or exceeded in successful comparable projects across the United States), an upfront capital contribution of about $150 million would be required for the project to cover its costs and generate a reasonable return on the remaining capital investment and ongoing operating costs. Although the City would not be expected to receive any financial return on this contribution, it would gain ownership of a citywide dark fiber network.

In this report, this scenario is called the base case. The base case includes the following major assumptions.

- The cost to construct is $194 million in nominal/year-of-expenditure dollars, per the cost summary described above in Table 1. (One way of relating this number to the $150 million number provided above is as follows: of this $194 million invested over the five-year construction period, $150 million would not be expected to generate any return.)
- The average revenue per user is $70 per month for consumers paying market rates and $30 per month for low-income consumers paying discounted prices in 2022 dollars, with prices increasing by 3 percent per year[1]
- Operating costs (described later in this report) are also assumed to increase by 3 percent annually
- The project achieves a take-rate of 40 percent after a five-year ramp-up period
- The project must generate a 10 percent internal rate of return (IRR), which would be expected to cover costs (other than the $150 million contribution) and produce a modest profit
- The project time horizon includes a five-year construction period and 25 years of operations

1.2.2 The magnitude of the required upfront contribution is highly sensitive to changes in pricing, take-rate, and construction costs

Because pricing and take-rate determine revenue, estimates of the required upfront capital contribution are highly sensitive to these factors. Changes in capex also significantly affect the required contribution.

The following changes to the assumptions relative to those in the base case would result in higher or lower required upfront contribution amounts.

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[1] The range of services could vary over time. As a frame of reference, $70 is in line with the current monthly cost of 1 Gigabit fiber services in other U.S. cities.

Pricing: If pricing is lowered by $10 for all subscribers, the required upfront contribution would increase to about $185 million. Conversely, if pricing is increased by $10 for all subscribers, the contribution would fall to approximately $120 million.

Take-rate: A more aggressive take-rate assumption of 50 percent would reduce the required contribution to approximately $125 million, while reducing it to 30 percent would increase the contribution to more than $175 million.

Capex: Using a 20 percent capex contingency would lower the required contribution to about $130 million. Increasing the capex contingency to 40 percent yields a required contribution of approximately $170 million.

Table 2 summarizes how changing in pricing and capex amounts affect the required contribution.

Table 2: Capex and pricing scenarios and their impacts on required contribution

Scenario/sensitivity	Upfront capital contribution amount		
Take-rate	30%	40%	50%
Baseline analysis (30% capex contingency)	$178M	$151M	$126M
Baseline analysis with $10 lower pricing	$206M*	$185M	$165M
Baseline analysis with $10 higher pricing	$152M	$121M	$91M
Baseline analysis with 20% capex contingency	$158M	$130M	$105M
Baseline analysis with 40% capex contingency	$199M*	$172M	$148M

* Exceeds overall capex[2]

Table 3 shows how take-rate affects the required upfront contribution amount, using the upfront contribution amount as an input and the required take-rate as the output.

Table 3: Required take-rate under different upfront contribution levels

Upfront contribution assumption	Required take-rate
$125 million in upfront capital contribution	51%
$150 million in upfront capital contribution (baseline analysis)	40%
$175 million in upfront capital contribution	31%

Variations in operating cost assumptions, the length of the operating period, and the desired or required IRR would also influence the upfront contribution. Section 4 provides a more complete discussion of these and other variables and their impact on the financial feasibility of the project.

[2] If the required upfront capital contribution exceeds overall capex, it means that the net present value of revenue is less than the net present value of all future operating costs. As such, the upfront contribution in such cases is effectively used to partially subsidize the future cost of operations and maintenance.

1.3 Four business models represent conceptual partnership approaches for Cambridge

The City could choose from four broad categories of business models that differ regarding the role the City or partners play across the three elements of the network: 1) Passive Infrastructure, 2) Active Infrastructure, and 3) Service Provision. All capital and operating costs of the network, and all contractual relationships with partners, fall into one of these three elements. Table 4 explains these elements. Table 5 summarizes the business model types. Section 5 describes these business models in greater detail.

Table 4: Network elements

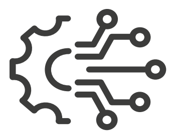
Passive infrastructure	Active infrastructure	Service provision
		
Building and maintaining the dark fiber network	Setting up and operating the active electronics on the network	Delivering broadband services to subscribers

Table 5: Business model types

Business model	Passive infrastructure	Active infrastructure	Service provision
1	Publicly funded/financed and maintained	Municipal ISP	
2	Publicly funded/financed and maintained	ISP (one or multiple)	
3	Publicly funded/financed and maintained	Active Infrastructure Contractor	Multiple ISPs / Open Market
4	(Largely) privately funded/financed, privately maintained, and operated		

1.3.1 Under Business Model 1, the City or another public entity fully funds, owns, and operates the citywide FTTP network

Under this model, the citywide FTTP network is fully funded, owned, and operated by the public sector, such as through a City-created Municipal Light Plant or MLP (see Appendix E: Massachusetts Municipal Light Plants). Alternatively, this entity outsources some of the operating responsibilities, but ultimately remains responsible for the project's success. This is the only business model in which the City would effectively have full control over all aspects of the broadband network construction, operations, and service provision. However, in this model the City would also fully retain the commercial (revenue) risk and all operating risk.

1.3.2 Under Business Model 2, the City would develop and maintain the passive infrastructure and contract one or multiple ISPs to provide active infrastructure and deliver service

In this model, the City would use public funding and/or financing to contract with a private entity to construct and maintain the Passive Infrastructure—that is, the dark fiber. The City would then lease access to the dark fiber network to one or multiple ISPs, who would in turn provide Active Infrastructure and Service Provision. The City would have the flexibility to structure a combination of lease fees and revenue sharing agreements to potentially partake in revenue upside scenarios.

In this model, the private ISP(s) would take the commercial and operating risk and would be incentivized to provide high quality service while compensating the City (or designee) for access to the Passive Infrastructure.

1.3.3 Business Model 3 mirrors Business Model 2, but the City would separately contract with an entity to develop and maintain the active infrastructure

Under Model 3, the City once again uses public funding and/or financing to contract with a private entity to construct and maintain the Passive Infrastructure. The City also would competitively procure and contract with a separate private entity to design, build, operate and maintain the Active Infrastructure component of the network. The Service Provision element of the network would be provided by multiple ISPs through an open market. Similar to Business Model 2, ISPs would lease access to the Passive and Active Infrastructure from the City, possibly in combination with a revenue share mechanism. This model is least proven in the United States.

1.3.4 Business Model 4 follows a public-private partnership (P3) approach, which transfers most risk to a private partner while allowing the City to retain long-term ownership

In Business Model 4, the City (or designee) would sign one contract with a single private entity that would be responsible for providing all elements of the citywide FTTP network including the Passive Infrastructure, Active Infrastructure and Service Provision. The private entity may subcontract for construction and/or maintenance of the Passive and Active Infrastructure.

Alternatively, the private entity may self-perform all work. However, under all these alternative contracting structures, the private entity would be the sole entity responsible for the full scope in its contractual obligation toward the City. In this model, public funding and/or financing contribution could still be used but a significant portion of the financing for all three scope elements will be provided by the private entity and its financiers. Under this business model, the City is maximizing its potential for long-term risk transfer through a Project Agreement with a P3 Partner. The P3 Partner has rights of use to the network during the Project Agreement, subject to terms and conditions imposed by the City.

1.3.5 All four business models can address the City's goals to varying degrees, but come with important tradeoffs

A comparative qualitative evaluation of the four business models shows that all models can, to varying degrees:

- Allow the public sector to retain long-term ownership of (at minimum) the Passive Infrastructure
- Allow the City to incorporate key public policy goals into contracts with private partners
- Increase choice and competition for subscribers
- Minimize the City's financial risk

The key tradeoff is between the objectives of retaining local control and transferring financial risk to the private sector, with Business Model 1 having the City retain most control but also exposing it to most financial risk while Business Model 4 transfers the most risks to a third party but also reduces the City's operational control.

Because the City does not have a municipal utility to leverage, it likely lacks the operational experience and expertise to be able to successfully implement a citywide network as required under Business Model 1. In this context, the team recommends Business Models 2 or 4, because we believe there are qualified partners willing to participate. Business Model 3 is far less prevalent and would require a further market sounding to identify partners who are both willing to participate and have a track record of doing so successfully.

1.3.6 Required City contribution could vary by choice of business model, depending on the partner and a variety of business factors

The financial feasibility analysis determines the required City contribution to reach a 10 percent IRR, with a variety of assumptions that include a 40 percent take-rate, regardless of how the project is financed or structured contractually. But it is important to note that in any of the partnership models, the magnitude of any required City contribution would also be influenced by other business factors. The eventual partner might be able to realize economies of scale by expanding existing operations or might have access to existing fiber or other network assets already present in Cambridge. Competition might even emerge among potential partners responding to a City procurement. These kinds of business factors could also influence the magnitude of any required financial contribution from the City—potentially to the City's benefit.

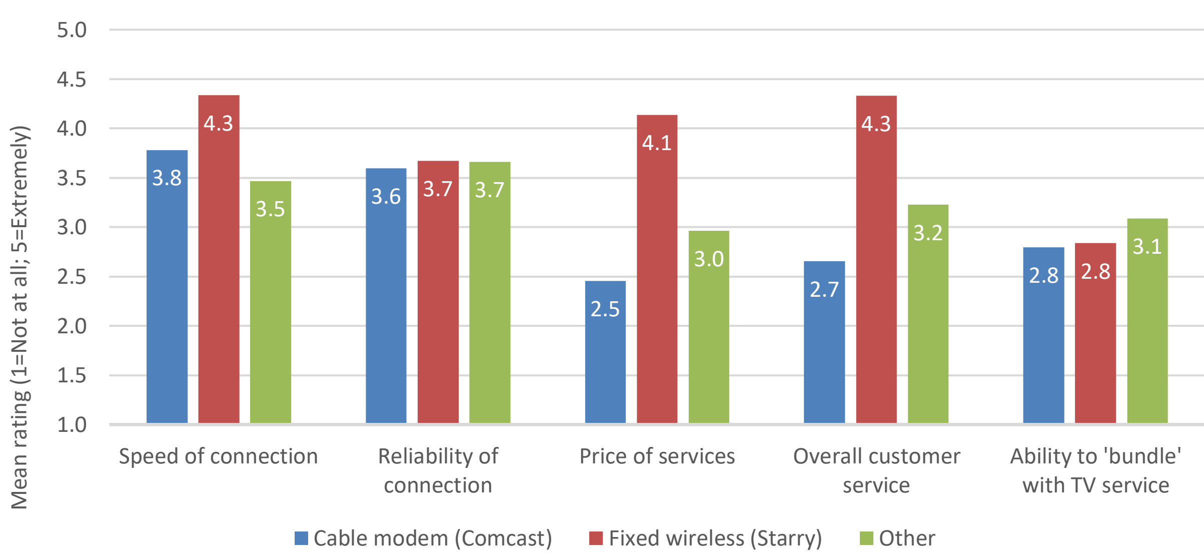
1.4 A scientific mail survey found strong public demand for a competing FTTP provider, even if a City contribution is required

CTC conducted a mail-based survey of Cambridge residents in May and June of 2022. In this effort, 5,000 survey packets were mailed first-class to a random selection of residential households—weighted to low-income households to compensate for historically lower returns from low-income households—with a goal of receiving at least 400 valid responses. The effort produced results with a high degree of statistical validity. A total of 604 surveys were completed and returned, significantly exceeding the goal. The full survey report describing methods and results is provided in Section 6. Selected datapoints are provided in the following subsections.

1.4.1 Cambridge Comcast subscribers expressed dissatisfaction and a strong willingness to switch

Eighty percent of respondents were Comcast subscribers; 8 percent were subscribers of Starry, a fixed-wireless provider that launched in Boston in 2017, subsequently expanded to Cambridge, and in early 2022 announced a partnership with the Cambridge Housing Authority (CHA) to provide service at CHA properties. (Other providers have market share only in the low single digits—as described in more detail in Section 6.) Comcast subscribers reported moderate degrees of satisfaction with their service across several categories, including connection speed, price, customer service, and ability to bundle, as shown in Figure 1. Respondents with service from Starry indicated higher satisfaction with their cost and customer service. Connection reliability was rated relatively equally.

Figure 1: Satisfaction with internet service aspects by primary internet service

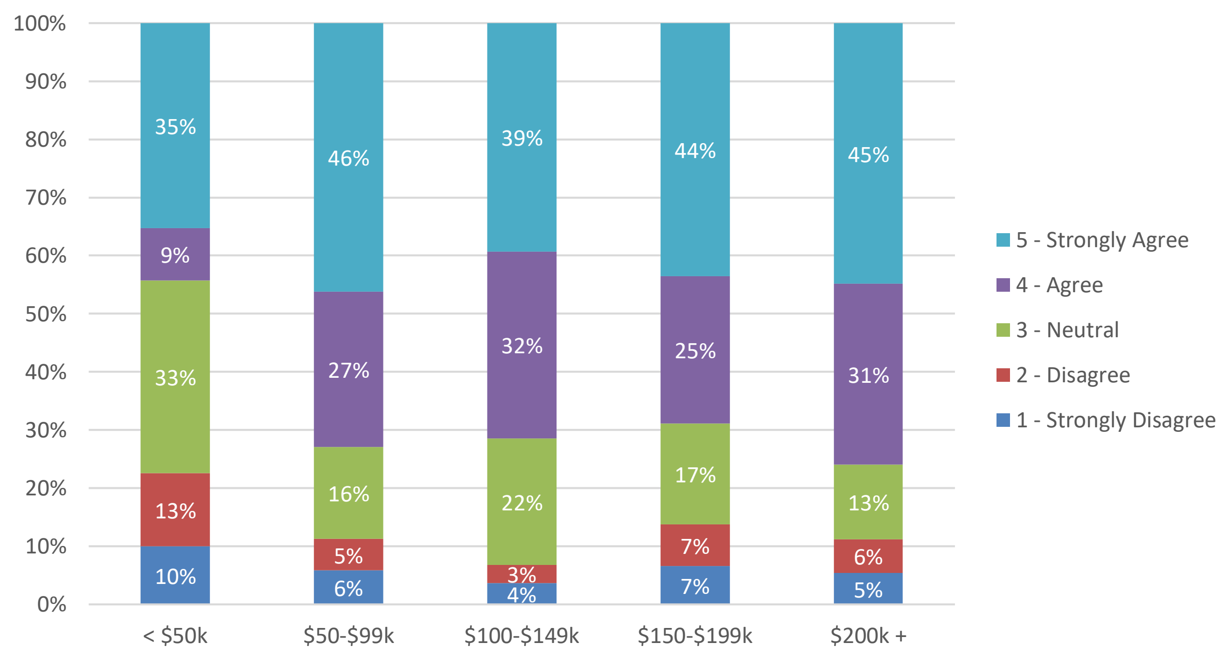


When asked if they would be willing to purchase services from a new provider, 58 percent of Comcast subscribers responded that they would be very or extremely likely to acquire new internet service, compared with 17 percent of Starry subscribers.

1.4.2 A large majority of Cambridge residents support City efforts to attract an FTTP provider and would support a City contribution

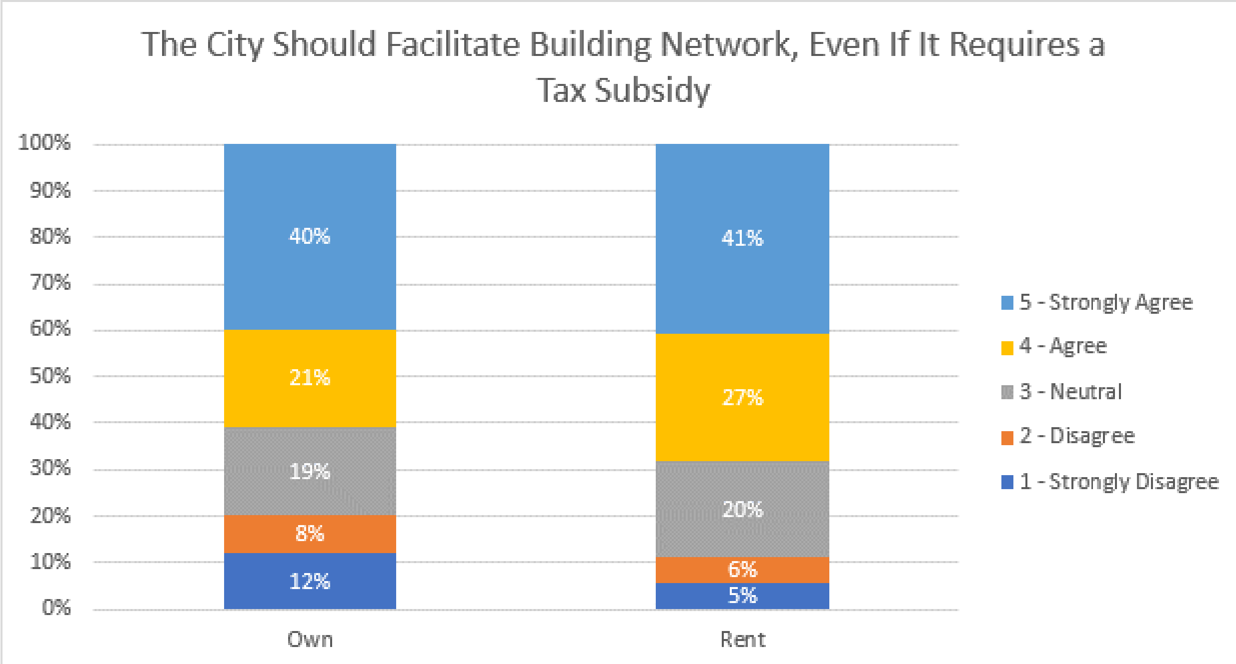
Eighty-seven percent of respondents agreed that Cambridge needs an additional internet service provider. When asked if they support City facilitation even if it required a contribution, two-thirds of respondents strongly agreed (40 percent) or agreed (26 percent) the City should facilitate building a fiber broadband network that allows for high-speed service and competition, even if this requires a tax subsidy. Figure 2 shows the overall results.

Figure 2: Agreement with "The City should facilitate building a fiber broadband network, even if this requires a tax subsidy from the City"



While the survey found that owners are somewhat more reluctant than renters to support a tax subsidy, there is still very strong support among owners, at 61 percent agreeing or strongly agreeing, compared to 68 percent for renters.

Figure 3: Level of agreement of owners and renters on the question of potential City subsidies



1.5 The broadband market in Cambridge is dominated by Comcast, making it attractive for a new FTTP provider, but fiber and fixed wireless competition is growing in parts of the City

Regardless of business model, the feasibility of a municipal broadband initiative depends in significant part on the level of market competition. As of late 2022, Cambridge was primarily served by Comcast for broadband service (that is, above 100 Mbps download, 20 Mbps upload). As noted above, the survey indicated that 80 percent of Cambridge residents are using Comcast. This dominance by one cable provider shows that the Cambridge market could look relatively attractive to a new FTTP entrant.

With that said, research conducted for this study showed moderate expansions by competitors even in the two years since the completion of the City's digital equity study. For example, certain new apartment complexes in Cambridge now have access to symmetrical fiber service (that is, providing high-speed service for both downloads and uploads) from Verizon Fios. And some residents have access to service from one or more high-speed fixed wireless providers.

More detail on the current state of broadband service in Cambridge is provided in Appendix C. Following is a summary of broadband market developments in Cambridge that could bear on the feasibility of a new municipal broadband offering.

- **Comcast may upgrade its technology:** Comcast has recently announced progress toward symmetrical gigabit service. In 2020 it claimed a successful test of 1.25 Gbps symmetrical service in Jacksonville, FL. In late 2022, the company said it will start offering "multi-gig symmetrical services to customers before the end of 2023."[3] The announcement did not specify which markets might be so served, and the industry has a history of making announcements of test results that do not quickly translate into widespread commercial deployments. But if this upgrade were to materialize, it would take a significant step toward closing the performance gap between cable service and FTTP. Even without this upgrade, Comcast has recently increased the speeds of its base residential product to 400 Mbps download, 10 Mbps upload.

- **Verizon is expanding fiber in targeted areas:** Until recently Verizon served Cambridge only with extremely slow DSL service, with very minor exceptions. However, several new apartment and condominium developments in East Cambridge, as well as three developments elsewhere in the City, are now able to get Verizon Fios service (shown in Table 6) according to our market analysis. A Verizon representative confirmed that Fios service was available in all but one case. This shows that even though Verizon has not stated any plans to build Fios in Cambridge, it is very willing to expand in targeted contexts, such as new construction. As a practical matter, it would be difficult for a new provider to successfully compete in these buildings. And if Verizon did decide to upgrade its legacy copper network to Fios throughout Cambridge—as it has done in 115 municipalities in Massachusetts, with several others announced in December, 2022[4]—the business feasibility of a second FTTP entrant would be significantly impaired.

Table 6: Developments in Cambridge offered Verizon Fios service

Developments with Fios FTTP service	Address
Sierra and Tango Condominiums	1 Earhart Street/2 Earhart Street
Elevate	1 Leighton Street
Park 151[5]	151 North First Street
Zinc	22 Water Street
Third Square Apartments	285 Third Street/303 Third Street
Watermark Kendall West and Watermark Kendall East	350 Third Street/250 Kendall Street
Tempo Cambridge Apartments	201 Concord Turnpike/203 Concord Turnpike
Vox on Two Apartments	223 Concord Turnpike
Atmark	80 Fawcett Street/90 Fawcett Street

[3] "Inside the Nation's Largest and Fastest Multi-Gig Network Deployment," Comcast, Press Release, Sept. 8, 2022, https://corporate.comcast.com/press/releases/comcast-expand-evolve-wifi-largest-multi-gigabit-network.
[4] "Verizon brings high-speed fiber internet to more Massachusetts customers," Verizon, Press Release, Dec. 2, 2022 Verizon brings high-speed fiber internet to more Massachusetts customers | About Verizon
[5] Verizon's retail interface offered Fios internet service to multiple units in this building; however, a Verizon company representative was not able to confirm that Verizon had Fios service on record at this location.

- **Starry market share:** Starry, the fixed wireless provider, holds an 8 percent market share in Cambridge, according to the survey conducted for this study, making it the second most used provider in the City. Starry filed for Chapter 11 bankruptcy protection in February 2023, yet says that its planned restructuring will enable it to continue to do business in Cambridge and other markets.[6] A company representative said the company intends to maintain its current network footprint and focus on growing its customer base within that footprint. Fiber will always be technically superior to fixed-wireless services, but survey data show high customer satisfaction with Starry's service. If Starry both survives its financial difficulties and succeeds in increasing its Cambridge customer base, any new provider will face commensurate challenges in the market.

- **Comcast price reductions:** Research by CTC indicates that as of late 2022 Comcast had reduced its 24-month promotional pricing for its gigabit product (1 Gigabit download, 35 Mbps upload) to $70 monthly, from $79.99 in 2020, although the post-promotion price was slightly higher. Price reductions and more attractive service plans—especially if combined with the implementation of symmetrical gigabit cable service—would make Comcast's gigabit product more competitive against a similar offering from a fiber provider.

- **Mobile providers now offer residential fixed wireless service**: Verizon and T-Mobile both offer fixed wireless service leveraging their mobile networks in some areas of Cambridge. In a random sample of addresses that included at least one from each of 12 neighborhoods in Cambridge (excluding the neighborhood with MIT's campus), several were offered this service from one or both providers. Such service is not only technically far inferior to fiber but can be throttled by the companies in times of mobile network congestion. Nevertheless, it does represent a new dimension to the Cambridge residential broadband market and could be chosen as an affordable option by some residential customers. For example, users of certain Verizon Wireless mobile plans can get the residential component (where available) for $25 monthly.
  - Verizon's residential fixed wireless service offers advertised speeds starting at 80 Mbps download, 10 Mbps upload. CTC found this offer at five of 12 Cambridge addresses checked in February 2023.
  - T-Mobile offers residential fixed wireless service with typical speeds starting at 33 Mbps download, 6 Mbps upload. This service was available at nine of 12 addresses checked.

[6] "Starry Files Voluntary Chapter 11 Petitions," Starry, Press Release, February 21, 2023, https://tinyurl.com/4ec98jt2.

More discussion on residential broadband pricing, availability, and competition in Cambridge is provided in Appendix C: Current state of broadband service, pricing, and competition in Cambridge, which describes the current state of broadband service in Cambridge.

1.6 Stakeholders voiced frustration with Comcast and expressed general support for City efforts

In addition to the survey, CTC engaged in a range of stakeholder outreach efforts. The efforts included engagement with business groups and individual businesses by means of meetings and online questionnaires distributed by the City and CTC, presentations to the Cambridge City Council in May and November of 2022, and a presentation to Upgrade Cambridge in May.

CTC sought any existing surveys, studies, or action plans developed by business groups or institutions around broadband. Although no such documents emerged from the process, most (but not all) business participants were supportive of City efforts to bring about a new FTTP provider. The effort surfaced complaints about Comcast customer service and pricing, but no reports that service was unavailable or that there was difficulty obtaining a direct fiber connection for businesses needing premium levels of service. Large companies and institutions in Cambridge willing to pay premium prices have robust options for obtaining enterprise-grade services from fiber providers.

The major institutions of higher learning—the Massachusetts Institute of Technology and Harvard University—expressed a willingness to continue the conversation and work cooperatively as the effort moves forward to determine areas of potential synergy, but did not offer specific commitments at this early stage regarding a specific willingness to contribute to the effort or obtain service from a new network. More detail and findings from these stakeholder engagements are provided in Section 7.

1.7 Cambridge has a roadmap for deploying an FTTP network with one or more private partners

The report includes an indicative roadmap that provides suggestions for next steps leading up to and through a potential procurement for one or more private sector partners for a City FTTP project. The City will benefit from a detailed evaluation of related procurements to determine key variables of its procurement approach such as the type and level of industry outreach to undertake prior to the launch of the procurement to market the project, the organization of bidder interaction during the procurement, the preferred bid parameter(s), and approaches to stimulating competition and innovation. A discussion of a potential roadmap to implementation is provided in Section 8.

2 Project overview

This report delivers on a primary goal of the City's Broadband Task Force, which recommended that the City procure a detailed municipal broadband feasibility and business analysis with robust costing and design elements that goes beyond the analysis published in the prior cost estimate commissioned by the City. The consulting team established—from Task Force themes, RFP language, and conversations with City staff over the course of the study—that the City's goals were as follows:

- **Fiber broadband network:** Develop realistic options for bringing about a financially sustainable and technologically robust fiber broadband network that serves the needs of all Cambridge residents and businesses for decades to come
- **Public ownership:** Ensure long-term ownership of (at minimum) the Passive Infrastructure, meaning the dark fiber network
- **Local control:** Give the City the ability to incorporate key public policy goals into contracts with any private partners
- **Affordability and equity:** Reach all low-income housing units and include a low-cost program to achieve digital equity with respect to accessing state-of-the-art broadband infrastructure
- **Choice and competition:** Bring about increased broadband choice and competition for subscribers
- **Minimize financial risk:** Create as little long-term financial risk to the City as possible

The consulting project involved the following major tasks:

- Producing a detailed FTTP design and cost estimate based on drive-outs of all streets in Cambridge and considering information from City staff to understand special construction conditions, awareness of recent inflationary pressures on materials and labor, and inclusion of suitable ranges and contingencies
- Developing a range of business and financial models for building, operating, and providing service to all premises in Cambridge—together with options for ensuring that low-income households will receive service at low or no cost
- Conducting a by-mail survey of Cambridge residents—conducted in a statistically valid way, crucial for understanding feasibility—which received a larger-than-expected return
- Engaged in discussions with major educational institutions, Upgrade Cambridge, Cambridge First, and BIPOC-owned businesses to gain perspectives on FTTP deployment.

(More extensive qualitative discussions are provided in the City's 2021 digital equity study.)

Antecedents to this report include the following:

- The City convened a Broadband Task Force that produced a report in 2016, and commissioned a fiber cost estimate without exploring feasibility.
- The Cambridge Housing Authority issued a broadband RFP resulting in engagement with Starry, a fixed wireless provider, to use rooftop space and provide competition within CHA properties.
- The City commissioned and, in early 2021, released a digital equity study; the study among other things developed data on digital equity gaps (in affordability, broadband skills, and device ownership) and made recommendations.
- The City, CHA, MIT, and private partners launched free outdoor Wi-Fi at Newtowne Court and Washington Elms.
- The City also provides free public internet access at select locations around the City, including at public libraries, schools, youth centers, parks, and fields.[7]

[7] "Cambridge Public Internet (CPI) Wi-Fi Access Points," https://www.cambridgema.gov/Departments/informationtechnology/CPI.

3 FTTP design and capital cost estimates

CTC developed a high-level fiber-to-the-premises (FTTP) network design and cost estimates to inform the City's broadband planning effort. The technical attributes reflected in the design and cost estimates are aligned with the City's goal of delivering robust fiber broadband services, providing end-to-end connectivity between every resident and business over long-lasting fiber optic infrastructure with capacity to support one or more competitive providers.

The design provides ubiquitous service within the Cambridge City limits, delivering residential services at symmetrical speeds of up to gigabit speeds and scalable to higher speeds with modest upgrades to electronics in the future.

The design entails a citywide FTTP distribution network footprint encompassing a total of approximately 19,500 standard "passings" that can be served directly with service drops extended from the FTTP distribution network in the City right-of-way and approximately 33,000 residential units located in multiple dwelling unit (MDU) structures. The design assumes that the FTTP distribution network is constructed aerially using existing utility poles to the extent determined feasible based on a citywide survey.

The total estimated capital cost of the network is $199.1 million in 2022 dollars, or approximately $3,803 per customer, assuming a 100 percent take-rate among the approximately 52,300 serviceable passings. This cost estimates includes:

- The associated engineering and fiber plant construction
- Redundant hub facilities to house core network electronics
- Network electronics, including customer premises equipment for each passing
- Customer service drops for each passing, including indoor cabling required for associated MDUs
- A 30 percent contingency to account for the high degree of volatility in the labor and material markets and other uncertainties associated with construction of an FTTP network.

3.1 Network architecture

The recommended architecture is a hierarchical data network that would provide scalability and flexibility, both in terms of initial network deployment and ability to accommodate the increased demands of future applications and technologies. The central characteristics of the fiber-to-the-premises data network include:

- **Service area:** provides service to all addresses within the Cambridge City limits

- **Capacity:** ability to provide efficient transport for subscriber data, including at peak levels, with support for over gigabit services
- **Availability:** high levels of redundancy, reliability, and resiliency; ability to quickly detect faults and re-route traffic; primary distribution forming diversely routed rings passing through each neighborhood
- **Efficiency:** no traffic bottlenecks; efficient use of resources and maximizing the use of existing assets, including utility poles and City conduit
- **Scalability:** ability to grow in terms of physical service area and increased data capacity, and to integrate newer technologies without new construction
- **Manageability:** simplified provisioning and management of subscribers and services; large fiber counts and access points capable of supporting a range of open access models; support deployment of active network components and redundancy closer to the customer than with traditional designs for self-healing backbone capabilities
- **Flexibility:** ability to provide different levels and classes of service to different customer environments; physical topology capable of supporting full spectrum of access technologies (GPON, XGS-PON, NG-PON2, Active Ethernet, etc.)
- **Security:** controlled physical access to all equipment and facilities, plus network access control to devices

This architecture offers scalability to meet long-term needs. It is consistent with best practices for either a single provider or an open-access network model to provide customers with the option of multiple network service providers. This design would support the current industry standard gigabit passive optical network technology. It could also provide the option of direct Active Ethernet services.

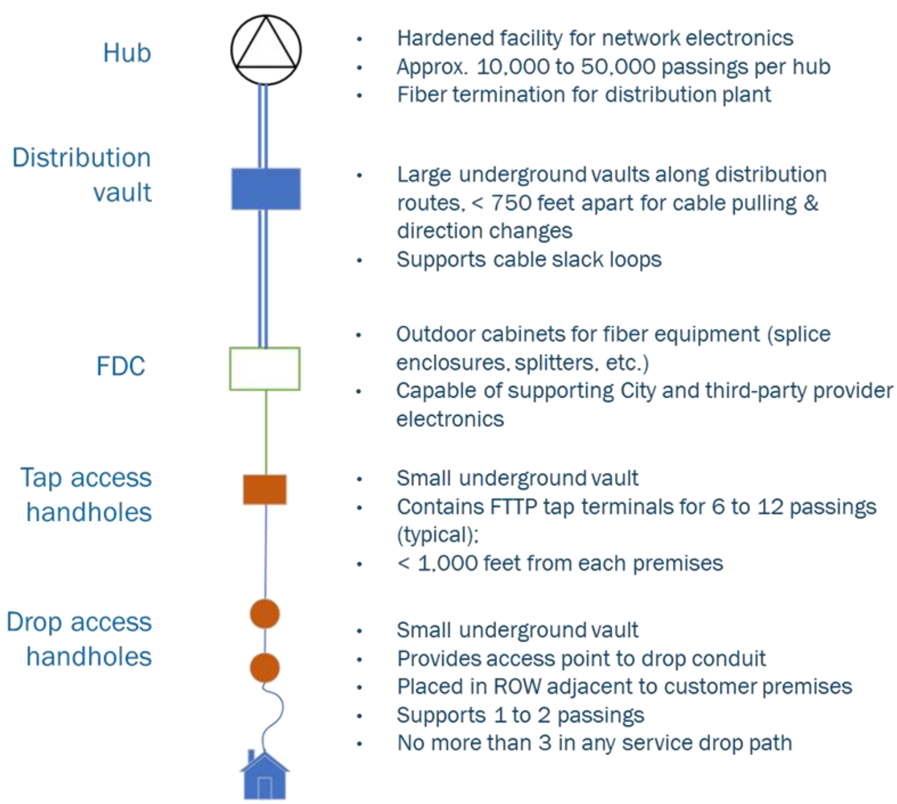
The design is based on a Gigabit Passive Optical Network (GPON) architecture, which is the most commonly provisioned fiber-to-the-premises service—used, for example, by AT&T Fiber, Verizon (in its FiOS systems), and Google Fiber. GPON supports high-speed broadband data and is easily leveraged by triple-play carriers for voice, video, and data services.

GPON uses passive optical splitting, which is performed inside fiber distribution cabinets (FDC), to connect fiber from the Optical Line Terminals (OLTs) to the customer premises where it connects to an Optical Node Terminal (ONT) on the outside or inside of the premises. With GPON service, the FDCs house multiple optical splitters that splits the signals from each OLT interface between approximately 64 customers, or fewer. The GPON OLT uses single-fiber (bi-directional) modules called SFPs (Small Form Factor Pluggable) which consists of a laser transmitter and a receiver to support multiple subscribers, so each customer receives a fiber connection all the way to the premises.

Figure 4 presents high-level representations of the fiber-to-the-premises network architecture used for the network design and the electronic components, illustrating the primary functional components in an FTTP network, their relative position to one another, and the flexibility of the architecture to support multiple subscriber models and classes of service.

A hub will feed primary distribution cables, passing through distribution vaults in underground segments, to fiber distribution cabinets containing splitters to feed secondary distribution cables to subscriber taps. The taps can be mounted to utility poles or located in small handholes located near residents. Service drops are installed between the tap and subscriber premises, placed inside drop access conduit in underground segments. The proposed design places drop access handholes located on the edge of the parcel within City right right-of-way to minimize the time and disruption required for new service drop installations in underground areas.

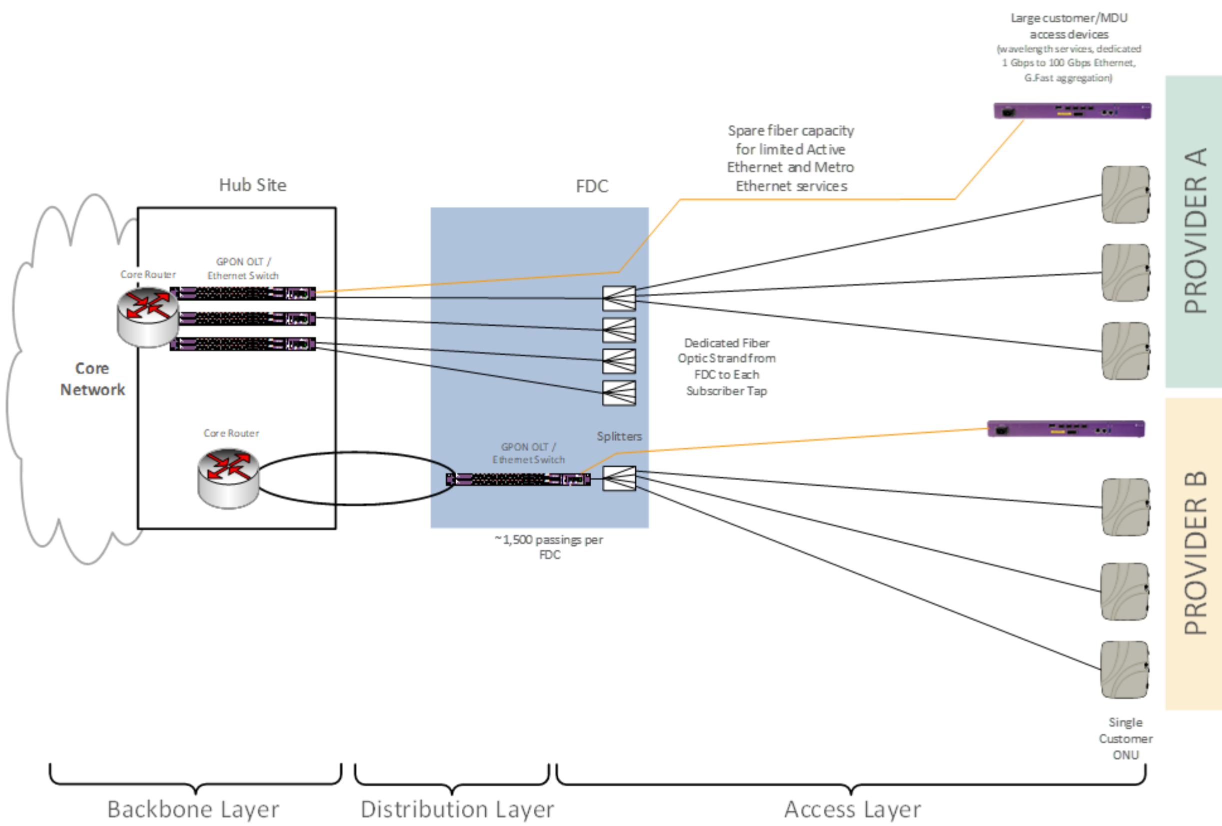
Figure 4: High-level FTTP architecture



A somewhat unique attribute of the proposed architecture is the "homerun" topology between the taps and the FDC, providing a one-to-one ratio between passings and fiber strands downstream from the FDC. This allows the architecture to support central deployment of distribution-layer electronics in the hubs, requiring only passive splitters in each FDC, or can allow a provider to deploy active distribution electronics at the FDC. This allows for delivery of multiple service tiers and types of services, potentially by multiple providers targeting different market sectors.

With physically diverse fiber paths between each FDC and the hubs, placing active electronics at each FDC enables the hub-to-FDC connection to be "self-healing" in the event of a fiber break with active electronics performing path protection switching over redundant uplink connections to the hubs. This might allow one provider to deliver residential and small business services cost effectively with centrally deployed electronics, and another provider serving the enterprise business market, including wireless providers, to provide more resilient services over redundant connections (Figure 5).

Figure 5: Network electronics and fiber component reference design



The chief advantage of this type of architecture lies in the simple passive design, which makes installation straight-forward and operations cost effective with few active pieces that can fail or that depend on electrical service in the field. GPON is limited to 1.2 Gbps upstream (in the upload direction) and 2.5 Gbps downstream (in the download direction) shared by all subscribers connected to a single PON interface through splitters. Split ratios of 1:64 or less are common for delivering gigabit per second services, though the proposed architecture anticipates split ratios of only 1:16 to meet increasing demands.

The physical architecture for GPON has proven to be versatile, with newer technology variants designed as upgrade paths that can coexist with GPON to deliver 10 Gbps services.[8] In fact, part of the attraction of GPON technology is that much of the infrastructure can be upgraded in a relatively easy and cost-effective manner. Some OLTs already support the next generation PON technologies (such as XGS-PON and NGPON2[9]), so much of the GPON investment can be reused, and upgrades can be done incrementally as needed.

The design assumes placement of manufacturer-terminated fiber tap enclosures within the public right-of-way or easements, providing watertight fiber connectors for customer service drop cables, and eliminating the need for service installers to perform splices in the field. This is an industry-standard approach to reducing both customer activation times and the potential for damage to distribution cables and splices. The design also assumes that the City or a partner obtains easements or access rights to private drives to access homes as needed.

3.2 Field survey overview

CTC conducted a field survey of the Cambridge City limits by a team of senior telecommunications outside plant (OSP) engineers. They completed physical walk outs and drives to survey 100 percent of the City's candidate public rights-of-way (ROW), identifying infrastructure conditions in all 156 street miles using custom real-time GPS/GIS tools. Field surveys provide valuable data on on-site infrastructure to inform cost estimates and market condition analysis.

The survey collected data on the presence of existing utility poles throughout the City and their condition, aiding in analysis of where aerial infrastructure deployments are possible and how much make-ready work may be necessary to accommodate new attachments. In particular, we sought to identify whether existing attachments would need to be relocated on the utility poles to provide the physical space necessary for a new attachment while maintaining clearances required by code – for example, there are specific clearance requirements between communications attachments and between the communications lines and the ground or other structures over which they pass. In cases where the height or condition of the pole will not accommodate a new attachment, the pole would need to be replaced with a taller pole. The particular costs for make-ready construction and pole replacements are determined by the utility

[8] Verizon, for example, is rolling out NGPON2 supporting 5G, as well as FiOS and business services. See https://www.lightwaveonline.com/fttx/pon-systems/article/14034625/verizon-full-speed-ahead-with-ngpon2-for-5g-mobile-support

[9] XGS-PON is an iteration of PON that can accommodate symmetric ("S") 10 ("X") Gbps service. NG (Next Generation) PON2 uses a different approach to achieve multigigabit bandwidth but can also use multiple frequencies, essentially allowing multiple PONs over the same fiber.

pole owner, generally subject to a negotiated pole attachment agreement. Based on our experience, we assume all costs associated with the new attachment would be borne by the City's FTTP project, including pole replacements, not including costs related to remediate existing non-compliance conditions, if applicable.

The surveys identified utility poles are available on 62.1 percent of the ROW, so the network design assumed 62.1 percent of the network to deploy aerial infrastructure, while the remaining 37.9 percent of the miles deploys underground.

The make-ready conditions of the surveyed poles were classified into types A, B, and C, each representing increasing levels of work necessary to prepare the poles for new cable attachments. The survey results were then used to develop an average make-ready cost per foot for each classification. A summary of the make-ready assessment is shown in Table 7. The utility pole make-ready costs are estimated to be approximately $4.1 million, based on the design encompassing a total of 130.0 route miles utilizing both aerial and underground infrastructure.

Table 7: Make-ready survey data and cost estimates (2022 dollars)

Make-ready attribute	Make-ready survey classification		
	Type A	Type B	Type C
Total estimated utility poles along routes of each classification	3,603	412	28
Percent of poles requiring make ready	25.0%	50.0%	75.0%
Cost per existing attachment relocation	$500	$500	$500
Percent of poles requiring replacement	5.0%	10.0%	25.0%
Average attachments per pole	1.0	2.0	2.0
Average poles per mile	50	50	50
Cost per pole replacement	$10,000	$10,000	$10,000
Estimated make-ready cost per foot	$8.29	$18.94	$42.61
Total Strand (ft)	380,443	43,552	2,989
Total Strand (mi)	72.05	8.25	0.57
Total make-ready cost	$2,837,112	$742,371	$114,631

3.3 Network design

3.3.1 Assumptions and criteria

The fiber-to-the-premises network design was developed with the following criteria based on the above assumptions and required characteristics of the hierarchical fiber-to-the-premises network:

- Fiber will vary between 12- and 288-count based on the projected need in the area.
- Underground conduit and fiber will be installed in the public right-of-way or in an easement on the side of the road.
- Aerial fiber will be installed on existing utility pole infrastructure.
- Backbone fiber sizes will range from 144- to 288-count cables; extended lateral fiber sizes will range from 48-to 144-count cable; and short lateral and drop fiber will contain 12 strands.
- The network will target up to 1,500 passings per secondary distribution point, each served from a fiber distribution cabinet (FDC) sized to house any combination of active equipment (GPON OLT, ethernet switches, etc.) and/or passive equipment (optical splitters).
- Distribution plant will terminate at multi-port subscriber tap terminals (i.e., “taps”) in underground handholes, each serving no more than 12 homes.
- Access conduit will be placed in drop access handholes placed at the edge of the parcel for each serviceable passing (one handhole per one or two passings).
- Underground vault spacing will be no more than 750 feet along distribution routes.
- Where possible, the distribution plant network routes will avoid crossing major roadways, railways, and waterways.
- Two hubs will be deployed to provide network redundancy in the case one network experiences failure.
- Fiber rings will be designs to provide route redundancy throughout the City in the case of line cuts or infrastructure damage

The cost of building a fiber-to-the-premises network will depend in large part on what percentage of the network infrastructure is built on aerial poles as opposed to inside underground conduit. Based on the field survey, the network design and cost estimates assume 62.1 percent aerial fiber and 37.9 percent underground fiber throughout the City.

As not all potential subscribers on the network will opt to subscribe to the service, cost estimates were produced assuming two different take-rate scenarios: 40 percent and 100 percent. That is, the costing model assumed 40 or 100 percent of the total passings of the network will choose to use the service. This quantity affects the costs of the network electronics needed to serve the network and the costs of deploying drops to subscribers on the network.

3.3.2 Network design maps

The resulting FTTP network is comprised of 130.3 route miles, consisting of 80.9 miles of aerial infrastructure and 49.4 miles of underground infrastructure. The design utilizes two hub sites and multiple fiber rings, providing redundancy and resiliency to network operations throughout the entire City. Figure 6 and Figure 7 display the backbone (hub to hub), primary distribution (hub to FDC), and secondary distribution (FDC to subscriber taps) layers of the final citywide FTTP network design.

Although the figures show the City Hall Annex and the Lexington Avenue Fire House as hub locations, these are merely indicative of potential sites and were chosen because of their central locations. The City has not made any determination about hub sites. These could be placed elsewhere in the City during the detailed design phase.

The design also deploys 42 primary Fiber Distribution Cabinets (FDCs), connecting the core hubs over fully diverse primary distribution routes. Each FDC supports serving up to 1,500 subscribers with passive and/or active electronics. As with the hub sites, the FDC locations shown in the figures are indicative of potential sites; actual FDC could be placed elsewhere.

The backbone route represents cable infrastructure building a ring between the network's two hubs, allowing them to communicate, transport, and backup network functionality. In the case one hub experiences extended failure, the other hub can maintain network operation. The primary distribution route connects the primary FDCs to the backbone ring, allowing the FDCs to transport data to and from the hubs. The FDCs act as major demarcation points through the City for ISP interconnections. The secondary routes build fiber into neighborhoods, bringing the infrastructure close to subscribers and preparing neighborhoods for fiber drops to subscribers' buildings.

Figure 6: Map of backbone and primary distribution routes

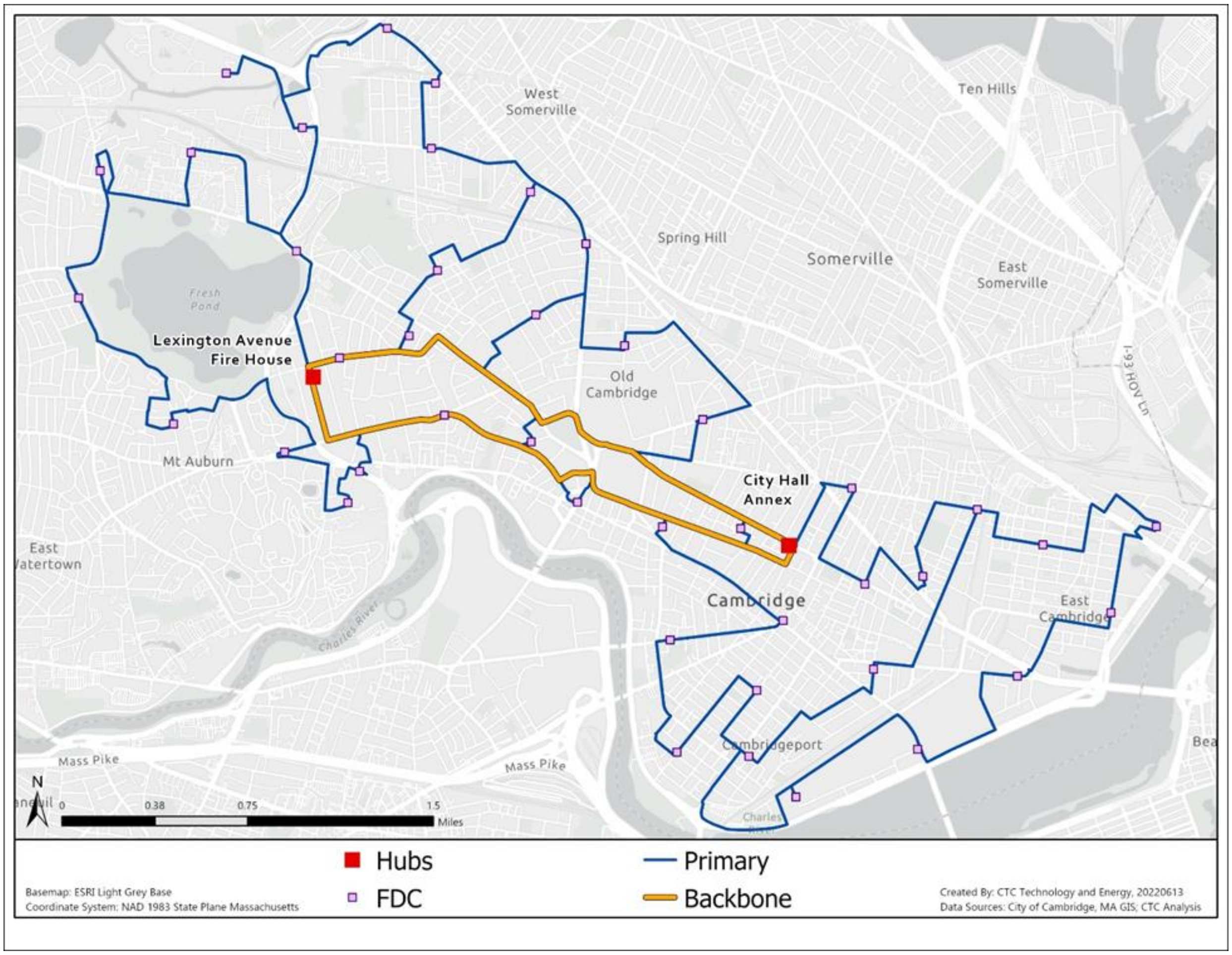
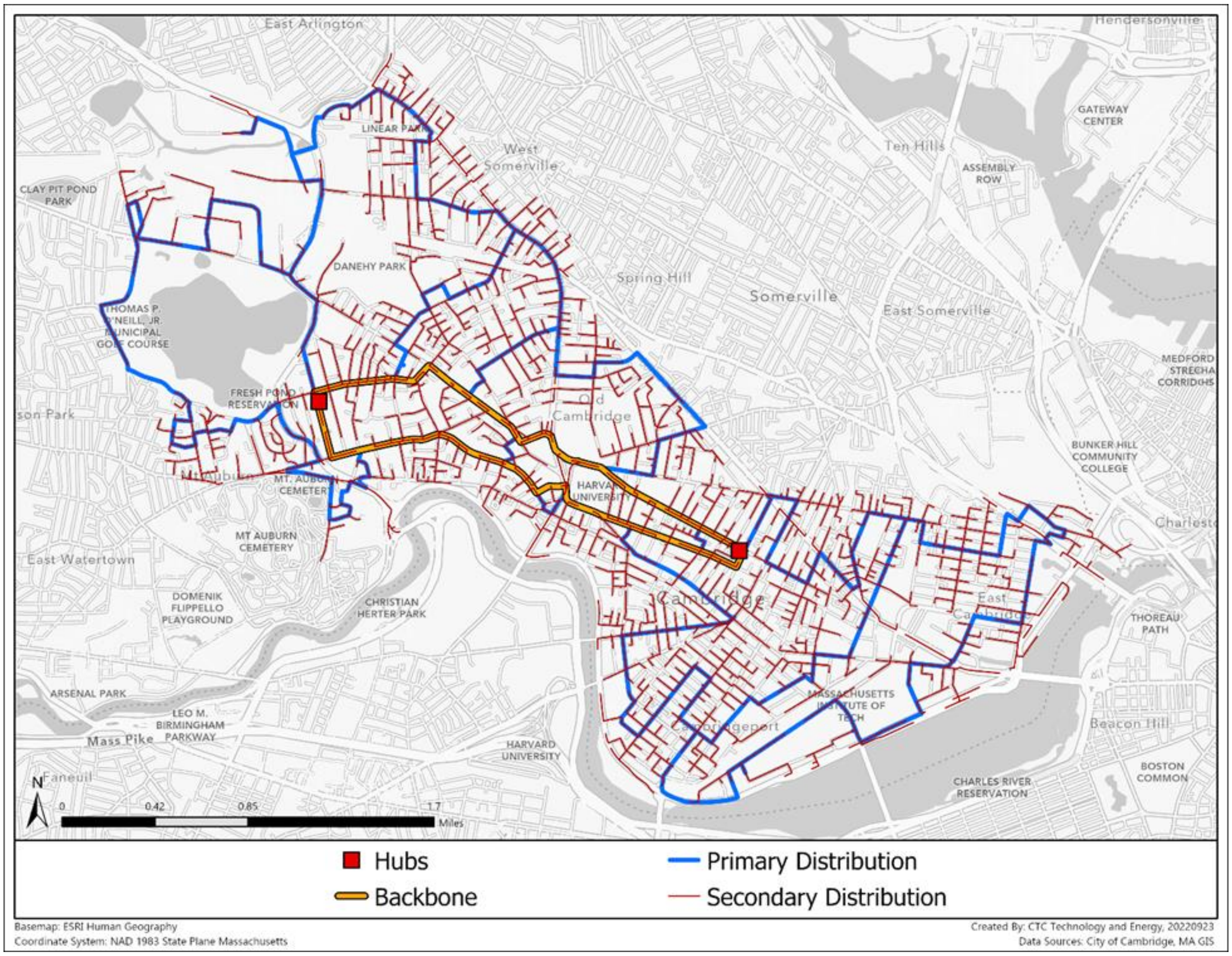


Figure 7: Map of backbone, primary distribution, and secondary distribution routes



The multiple layers of the FTTP are shown in greater detail for a small portion of the network in Figure 8 through Figure 11, including the access layer comprised of subscriber drop pathways to each passing. The combined infrastructure illustrating the depth of the end-to-end fiber infrastructure along each roadway and to each home is shown in Figure 11. The cost estimate presented in this document are based on a design of this detail generated on a citywide basis.

Figure 8: Sample map of FTTP primary distribution layer

Figure 9: Sample map of FTTP secondary distribution layer

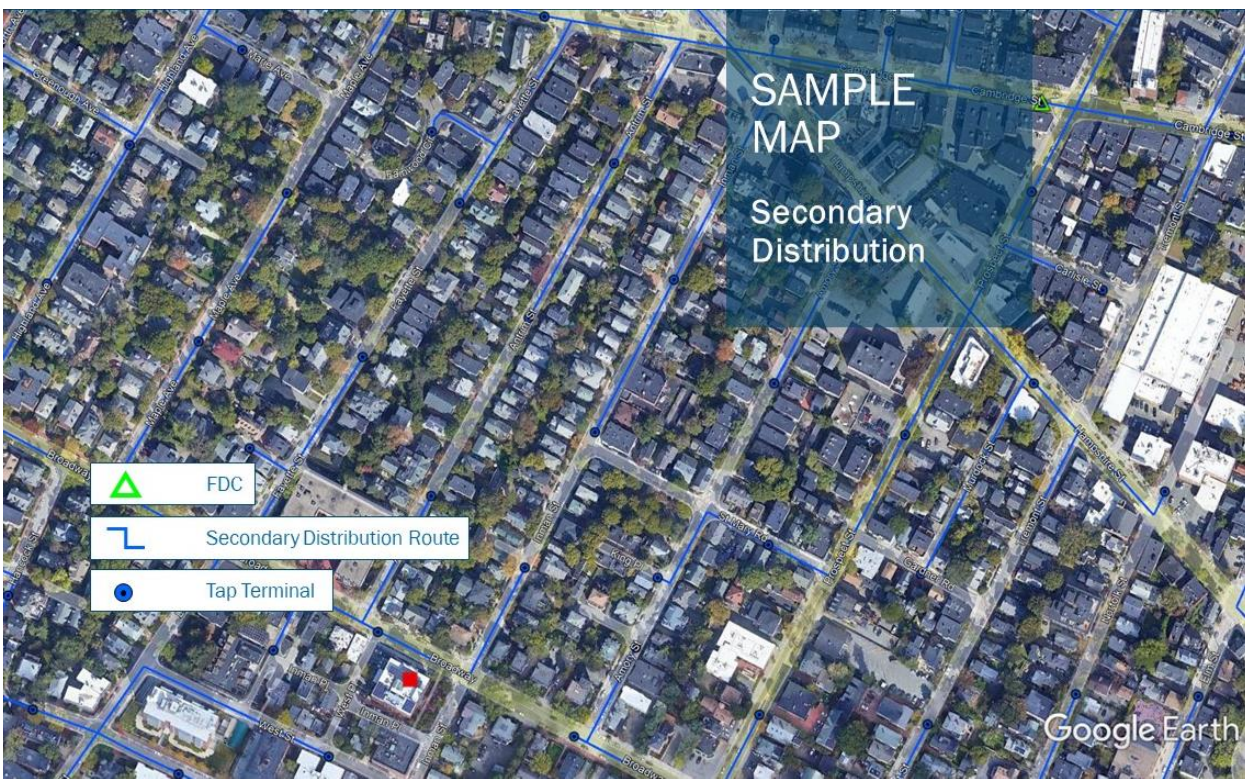


Figure 10: Sample map of FTTP access layer

Figure 11: Sample map of FTTP combined distribution and access layers

3.4 Estimated FTTP capital costs

The cost for the backbone and distribution plant includes the following elements:

- **Project management** encompasses overall project and contract management, including oversight of the construction and engineering contractor(s), equipment suppliers, and right-of-way agreements; the estimate assumes a 2-person project management team for a five-year deployment period.
- **Engineering and as-builts** includes system-level architecture planning, preliminary designs, and field walk-outs to determine candidate fiber routing; development of detailed engineering prints and preparation of permit applications; and post-construction "as-built" revisions to engineering design materials. These costs were assumed to be 15 percent of the backbone, distribution, and MDU cabling capex.
- **Conduit and vault infrastructure** consists of all labor and materials related to underground communications conduit construction, including conduit placement, vault/handhole installation, and surface restoration; includes all work area protection and traffic control measures inherent to roadway construction activities.
- **Utility pole make-ready** consists of the labor needed for preparing poles for the addition of new aerial cabling. This includes moving existing cables to make room for new cables or replacing poles if the existing pole is at maximum capacity. These costs utilize the make-ready data developed from the engineering field surveys.
- **Fiber optic cables and components** consists of the material and labor costs specific to the installation of fiber optic cables, taps, splice enclosures, and other related components, irrespective of the cable pathway (underground conduit or aerial placement).
- **Fiber splicing, testing, and documentation** includes all labor related to splicing of outdoor fiber optic cables.
- **Hub site facilities and systems** consists of the material and labor costs of placing head end and active hub site shelters and enclosures; related hub systems (backup power generation, cooling systems, etc.); and terminating backbone fiber cables within the head end and active hub site.
- **City construction oversight and police detail** consists of City-related costs for construction inspection and oversight, including required police details for traffic safety for work occurring along City roadways.
- **Core electronics** consists of core routers, aggregation switches, network security components, and network management systems. These components are sized to support the entirety of the network and generally do not vary with take-rate.

- **Distribution electronics** consists of distribution-layer network electronics providing the connections between the customer premises equipment (CPE) and the core provider core electronics, specifically including XGS-PON optical line terminal (OLT) hardware. These components are generally modular and scale with the take-rate to meet subscriber demand.
- **Customer activation costs** consists of standard subscriber service drop construction, where applicable, CPE, and related installation and service provisioning costs incurred for each new subscriber.

The cost estimate was generated based on our experience in other similar communities, including pricing resulting from recent competitive bid processes, and was informed by Cambridge-specific data points offered by the City and the CHA. In particular, this included:

- Address data from the City's GIS systems
- Unit pricing data for underground construction provided by the City's Department of Public Works
- Building configuration details for public housing provided by the CHA

Table 8 presents a breakdown of the estimated FTTP costs of approximately $123.9 million and $153.2 million, or $5,923 and $2,929 per subscriber, for the full FTTP buildout for take-rates of 40 percent and 100 percent, respectively, not including contingency. As not all potential subscribers will choose to subscribe to service, the 40 percent take-rate estimate provides a more likely near-term to mid-term cost, whereas the 100 percent take-rate estimate provide a conservative estimate as to the higher end of what the network could potentially cost. The figures in Table 8 are in 2022 dollars and do not account for inflation.

Table 8: Estimated capex in 2022 dollars

Cost attribute	Estimated costs	
	40% Take-rate	100% Take-rate
Project management & engineering	$15,550,000	$15,550,000
Utility pole make-ready	$4,100,000	$4,100,000
Aerial strand construction (labor & materials)	$1,600,000	$1,600,000
Conduit infrastructure construction (labor & materials)	$34,300,000	$34,300,000
Fiber optic cables and components	$4,050,000	$4,050,000
Fiber splicing, testing & documentation	$1,100,000	$1,100,000
Hub facilities	$1,000,000	$1,000,000
MDU laterals and cabling	23,200,000	23,200,000
City construction oversight & police detail	$11,500,000	$11,500,000

Cost attribute	Estimated costs	
	40% Take-rate	**100% Take-rate**
Core network electronics	$7,850,000	$7,850,000
Total fixed cost	**$104,250,000**	**$104,250,000**
Fixed cost per passing	$1,994	$1,994
Distribution electronics cost	$4,200,000	$10,250,000
Customer activation cost *(includes standard service drops & CPE for standard and MDU customers)*	$15,450,000	$38,650,000
Total cost (without contingency)	**$123,900,000**	**$153,150,000**
Total cost per customer	$5,923	$2,929
Contingency (30%)	$37,170,000	$45,945,000
Total cost (with contingency)	**$161,070,000**	**$199,095,000**
Total cost per customer	$7,700	$3,807

Applying a 5 percent inflation over a five-year buildout period starting in Q1 2024 results in the nominal (i.e., year-of-expenditure) capex shown in Table 9, which is the actual amount of money the City or a private partner would have to mobilize to build the project.

Table 9: Estimated capex in nominal dollars

Cost attribute	Estimated costs	
	40% Take-rate	**100% Take-rate**
Project management & engineering	$18,360,000	$18,360,000
Utility pole make-ready	$4,840,000	$4,840,000
Aerial strand construction (labor & materials)	$1,890,000	$1,890,000
Conduit infrastructure construction (labor & materials)	$40,490,000	$40,490,000
Fiber optic cables and components	$4,780,000	$4,780,000
Fiber splicing, testing & documentation	$1,300,000	$1,300,000
Hub facilities	$1,180,000	$1,180,000
MDU laterals and cabling	$27,390,000	$27,390,000
City construction oversight & police detail	$13,580,000	$13,580,000
Core network electronics	$8,810,000	$8,810,000
Total fixed cost	**$122,620,000**	**$122,620,000**
Fixed cost per passing	$2,345	$2,345
Distribution electronics cost	$5,610,000	$13,690,000
Customer activation cost *(includes standard service drops & CPE for standard and MDU customers)*	$20,630,000	$51,620,000

Cost attribute	Estimated costs	
	40% Take-rate	100% Take-rate
Total cost (without contingency)	**$148,860,000**	**$187,930,000**
Total cost per customer	$7,117	$3,594
Contingency (30%)	$44,660,000	$56,380,000
Total cost (with contingency)	**$193,520,000**	**$244,310,000**
Total cost per customer	$9,252	$4,672

3.5 Alternative buildout scenarios

In addition to the cost estimate for the primary buildout scenario described above (which we will call Buildout Scenario 1 for the purposes of this subsection), cost estimates are provided for three additional buildout scenarios (see Table 10 below) that vary primarily with respect to:

- The degree to which the infrastructure extends onto the private property and to each residential unit of multiple dwelling unit (MDU) developments, in particular those containing low-income housing; and
- The mix of aerial and underground construction.

The three additional scenarios significantly increase the cost per passing and, in turn, significantly impair the project's financial feasibility.

With that said, each of the buildout scenarios assumes a citywide FTTP distribution network footprint encompassing a total of approximately 19,500 standard passings that can be served directly from service drops from the FTTP distribution network in the City right-of-way. Except for buildout scenario 2, which provides an upper-end cost estimate assuming entirely new underground fiber infrastructure, all buildout scenarios assume the FTTP distribution network is constructed aerially using existing utility poles to the extent determined feasible based on a citywide survey. The four buildout scenarios are summarized as follows:

- **Buildout Scenario 1 (described above):** estimates the cost for connecting all standard residential and business passings, including a total of approximately 19,500 standard passings that can be served directly from service drops from the FTTP distribution network in the City right-of-way and approximately 33,000 residential passings within MDUs via a mix of underground and aerial fiber plant.
- **Buildout Scenario 2:** estimates the cost for connecting all standard passings, including all MDUs in the City, using only underground fiber deployment.

- **Buildout Scenario 3:** estimates the cost for connecting all standard passings and all MDUs containing any affordable housing—meaning Cambridge Housing Authority (CHA) units and other subsidized affordable housing units—but excluding market rate MDU units.[10]
- **Buildout Scenario 4:** estimates the cost for connecting all standard passings and only CHA units—not any other MDUs whether market-rate or subsidized affordable units.

Table 10: Estimated FTTP buildout scenario capex estimates at 100 percent take-rate (2022 dollars)

Scenario attribute	Buildout scenario 1	Buildout scenario 2	Buildout scenario 3	Buildout scenario 4
MDU coverage	All	All	Only affordable housing and CHA MDUs	Only CHA MDUs
Aerial vs. underground	Aerial & Underground	Underground only	Aerial & Underground	Aerial & Underground
Standard passings	19,400	19,400	19,400	19,400
MDU passings	32,893	32,893	16,150	2,668
Total passings	52,293	52,293	35,550	22,068
Fixed costs	**$199.1 million**	**$306.6 million**	**$163.7 million**	**$134.9 million**
Fixed cost per customer	**$3,803**	**$5,863**	**$4,605**	**$6,111**

[10] Affordable housing includes those homes owned by the Cambridge Housing Authority (CHA) and MDU structures containing any percentage of privately-owned housing available to eligible residents through the City's Inclusionary Housing Rental Program, Section 8 housing vouchers, and other similar affordable housing programs.

4 Financial feasibility analysis

The financial analysis in this section examines the financial feasibility of a ubiquitous citywide fiber-to-the-premises network built with a mix of aerial and underground construction, following existing utility installations in Cambridge. To do so, the project team developed a custom financial model that compares projected capital expenditures (capex) and operating expenditures (opex) with projected revenues, which depend on certain assumptions about "take-rates" and average revenue per user (ARPU). Take-rate is defined as the percentage of customers that subscribe to the citywide FTTP network out of all potential customers that the network could potentially serve.

This financial feasibility analysis does not include assumptions around how the citywide FTTP network is funded or financed, but simply assesses whether the project requires external funding for it to be financially feasible based on the fundamentals of the operational cash flows (revenue, capex, and opex). To do so, the financial model calculates the internal rate of return of the project (project IRR) using the operational cash flows over the construction period and 25 years of operations, which provides an indication of the overall attractiveness of the project from a purely commercial perspective.

To evaluate financial feasibility, the analysis determines what combination of take-rates and public funding, if any, would be necessary to achieve a sufficient project IRR given certain assumptions about ARPU (as explained below).

The dollar figures and take-rates discussed in this report reflect the economics of a new-build project by a non-incumbent internet service provider (ISP). The financial profile of a citywide FTTP project developed by the incumbent provider in Cambridge may differ significantly as the incumbent can take advantage of material synergies in expanding and operating its existing network.

The next sections describe in more detail the financial feasibility analysis introduced above. This includes an evaluation of the key drivers of capex, opex, and revenues that affect project feasibility. For each section, the graphs show the financial model outputs for a ubiquitous fiber buildout—that is, a full citywide rollout that is 62 percent aerial, 38 percent underground, and builds into and throughout all multi-dwelling units (MDU). Other potential construction scenarios—such as building entirely underground or building only to affordable housing MDUs and not market-rate buildings—would be more expensive per passing. These less-feasible scenarios are discussed in Section 4.9.

Based on the key inputs, this section provides financial feasibility outputs and discusses the implications for City decision-making.

Building on the financial feasibility results, this section also provides a sensitivity analysis, illustrating the degree to which key outputs change as a result of modifications in key capex, opex and revenue inputs.

4.1 Passings and subscribers

Capex contains both a fixed component and a variable component, which is driven by the number of customer activations. An important intermediate step for calculating subscriber-driven costs and revenue is the determination of the number of passings available and number of subscribers throughout the forecast period. A passing is considered available once the outside plant reaches the street outside a given building and the core network equipment necessary to operate the network is in place.

At this point, in order for a new subscriber to be connected to the network, an ISP only needs to construct a drop and install the customer's equipment to begin service. The estimated number of subscribers is the product of the number of available passings and the take-rate at any point in time. The following graph illustrates the interrelated dynamics of network construction and new subscriber growth in the early years of the forecast period.

A hypothetical steady state 40 percent take-rate is used to show these interrelated dynamics visually and is not an input or assumption in our financial analysis, as we will explain in more detail below.

Figure 12: Passings, drops, subscribers, and take-rate

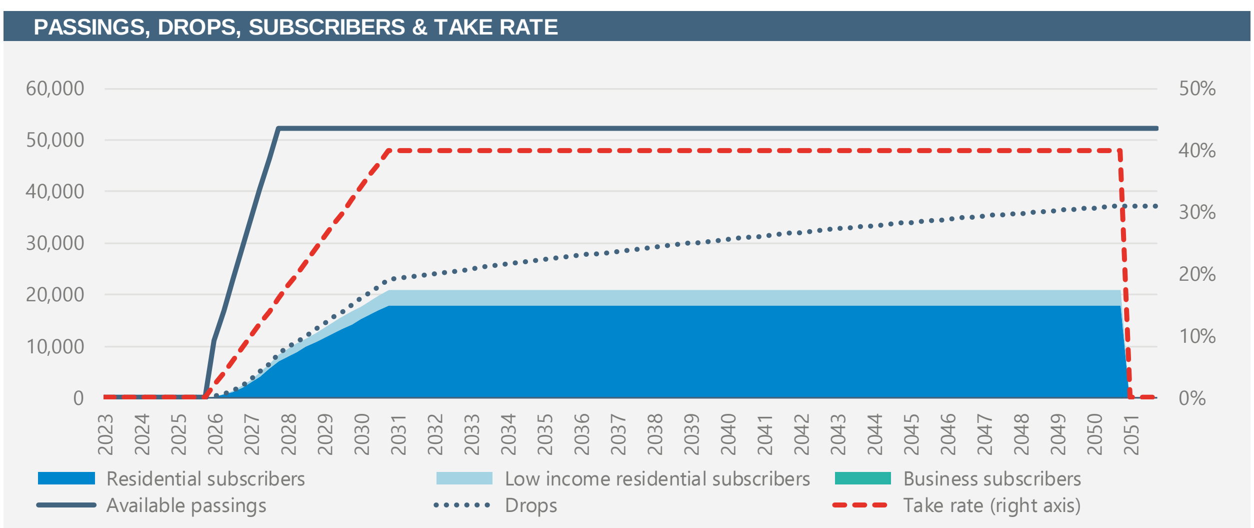


Table 11: Available passings, drops, and subscribers (year 2031)

Item	Value
Available passings, 2031	52,293
Drops built, 2031	23,720
Residential subscribers, 2031	17,884
Low-income residential subscribers, 2031	3,033
Total subscribers, 2031	20,917

In the third year of construction (from Q1 2026 onward), the full footprint of the citywide network is still being built out and new passings are continuously being made available. At the same time, drops are beginning to be constructed and new subscribers are being brought onto the network. In other words, during the third, fourth, and fifth year of construction, outside plant construction and network operations occur simultaneously, and the ISP is already collecting revenue even before the network is fully finished and all passings are made available.

Once construction of the outside plant is completed by the end of 2028, all passings will have been built, but the provider continues to add new drops at the completed passings as new customers subscribe to the network over a five-year ramp up period until the take-rate reaches a long-term steady state.

The financial model also assumes 5 percent annual subscriber churn, which means that each year, 5 percent of customers are assumed to be disconnecting from the network with another 5 percent of new subscribers taking their place, maintaining the same overall number of network subscribers. (This percentage considers the fact that Cambridge has many college student residents, which may result in more churn than in areas without such populations.) For some of these new subscribers, a new drop will need to be constructed if no drop was previously installed. This explains why the number of drops continues to grow in the chart above, even though the number of subscribers remains constant. As more drops are built, the likelihood of having to build another drop for a new subscriber decreases because the number of passings without a drop has declined with each new drop constructed.

4.2 Capex

The capex consists of both upfront capex and capital renewal to replace assets that have reached the end of their useful life within the forecast period. Within upfront capex, some costs are fixed while others are tied to customer activations. The methodologies that the project team used to produce the upfront capex cost estimates are outlined in detail in Section 3. Capex is expressed in 2022 dollars, unless stated otherwise.

The fixed upfront capex is driven primarily by the cost of the outside plant and contains the core network equipment. The fixed upfront capex is incurred during the construction period, which is projected to start in Q1 2024 and extends through Q4 2028.

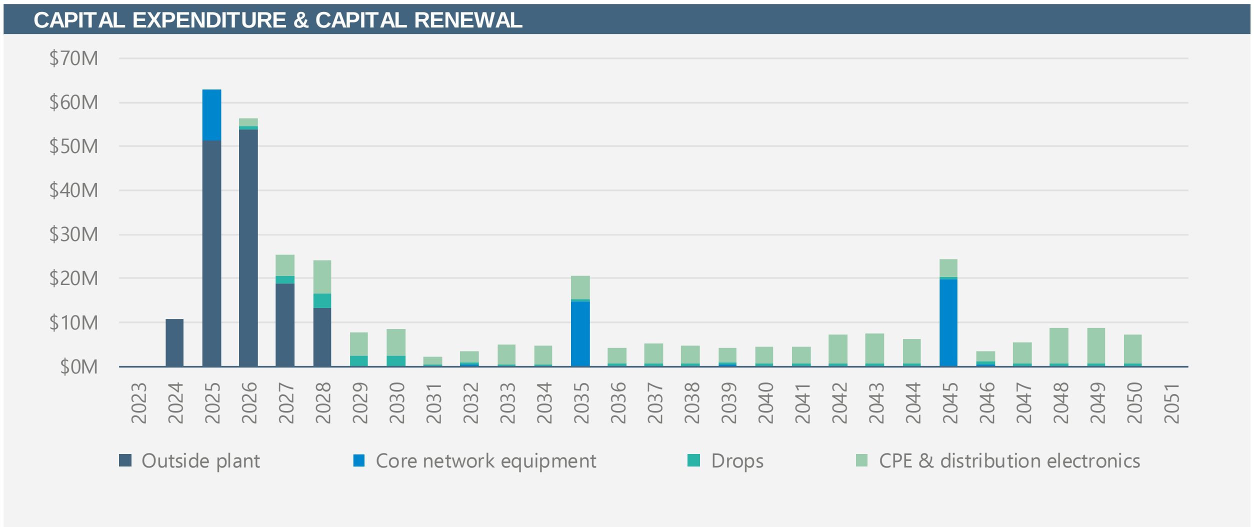
The variable upfront capex consists of consumer premises equipment (CPE), distribution electronics, and customer drops, which all depend on the number of active subscribers and therefore depend on the assumed take-rate. The construction of the drops is projected to commence in Q1 2026 and continue at a steady pace through Q4 2030 (i.e., a five-year ramp up period), at which point the project take-rate is expected to reach a steady state.

As discussed above, additional drops will continue to be added over time because of subscriber churn. These additions are not considered to be part of the upfront capex but are still part of the project's overall capex. The construction of these future drop additions will likely be funded from operating cash flows and will likely not need to be financed.

Although outside plant and drops may require maintenance in the form of repairs throughout the life of the project, they will not need to be replaced because the useful life is many decades. Network electronics and CPE on the other hand do need to be replaced from time to time. More specifically, core network equipment is projected to be replaced every 10 years whereas distribution equipment is expected to have a useful life of seven years. Furthermore, the optical network terminal (ONT) and uninterruptible power supply (UPS) are expected to have a useful life of five and three years, respectively.

The following graph shows the upfront capex (fixed and variable), capex associated with future drop construction, and capital renewal of equipment over the course of the entire forecast period, expressed in nominal dollars. For the purposes of displaying the data visually, we use a steady state take-rate of 40 percent for the variable capex.

Figure 13: Estimated capex and capital renewal in nominal dollars



4.3 Take-rates

The following is not a discussion of a specific input into the financial model, but instead provides a frame of reference for understanding feasibility through the lens of take-rates—that is, the percentage of potential customers who take service. The team analyzed the take-rates achieved by other municipal FTTP operators in the United States.

In general, take-rates of new broadband competitors are dependent on the types of market competition present. If the only competition is DSL (such as in rural areas) it is common to achieve take-rates at percentages well into the 50s and beyond. When the competition is cable (such as in Cambridge) and incumbent telcos decide to upgrade to fiber, take-rates of those telcos typically plateau at percentages in the high 30s or low 40s. (In Cambridge the incumbent telco, Verizon, has not elected to upgrade to fiber.)

Demographics play a significant role; higher-income residents tend to subscribe at higher rates. However, success in the highly competitive broadband business does not only depend on demographics and competition but also on quality execution and ongoing marketing.

Some of the more successful municipal broadband businesses in the United States have achieved take-rate percentages in the 40s and 50s. These are not predictors of what would occur in Cambridge but do reflect what is possible if the project is successfully executed and marketed.

Competitive suburban markets often see take-rates in the low 30s. Some municipal networks have only achieved take-rates in the 20s, which can typically be attributed to either poor execution and/or lackluster marketing. Municipal FTTP networks that plateau well below 40 percent take-rates are affected by a mix of factors, such as competition from both cable broadband and telco FTTP and location in a suburban market.

For example, two Massachusetts Municipal Light Plants (MLP) running broadband businesses—Norwood and Braintree—established their businesses in the context of facing competition only from the cable provider, but later faced additional fiber competition from Verizon Fios. Norwood was able to hold much of its market share, but Braintree's MLP recently quit the business and sold its cable operation to Comcast. (Appendix E contains a discussion of MLP structures.)

Cambridge currently does not resemble either of those communities because it lacks a fiber competitor. Furthermore, survey results (see Section 6) show strong general support for a new competitor. While responding to a survey is not the same as acquiring services (or doing so at any particular price point), it does show support among Cambridge residents.

4.4 ARPU and revenue

The subscription revenue forecast in the financial model is developed using the estimated number of subscribers at each point in time and multiplying that number by the ARPU. The financial model distinguishes between low-income residential subscribers, to which a lower ARPU applies, and full paying residential subscribers, to which a higher ARPU applies.

The financial model assumes an ARPU of $70 per month (in 2022 dollars) for full paying residential subscribers at the start of operations. This matches what Google Fiber[11] is offering in other jurisdictions in the U.S. for comparable 1 Gbps symmetrical broadband service and is well below Ting Internet's 1 Gbps offering of $89 per month.[12] Although other ISPs, such as Metronet, are offering a symmetrical Gig for $60,[13] we believe a $70 ARPU is a reasonable price point for Cambridge given its high build cost, relatively wealthy population, and robust willingness to pay, as demonstrated by the survey results (see Section 6).

The low-income residential ARPU figure is estimated at $30 per month at the start of operations, which is in line with pricing that other providers are offering to low-income residential subscribers under the federal Affordable Connectivity Program (ACP). Under this assumption, low-income subscribers effectively pay nothing, and all revenues are derived from the ACP subsidy.

It should be noted, however, that the ACP has a limited pool of $14.2 billion in funding, which may run out at some point in the next two years. The assumption that low-income customers can get a no-cost service using the ACP at the time a new Cambridge service starts up requires that Congress adds funding—or that some other entity, such as the Commonwealth of Massachusetts, steps in to replace the subsidy.

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[11] https://fiber.google.com/, accessed on January 1, 2023.

[12] https://blog.ting.com/internet/ting-internet-pricing-promise, accessed on January 1, 2023.

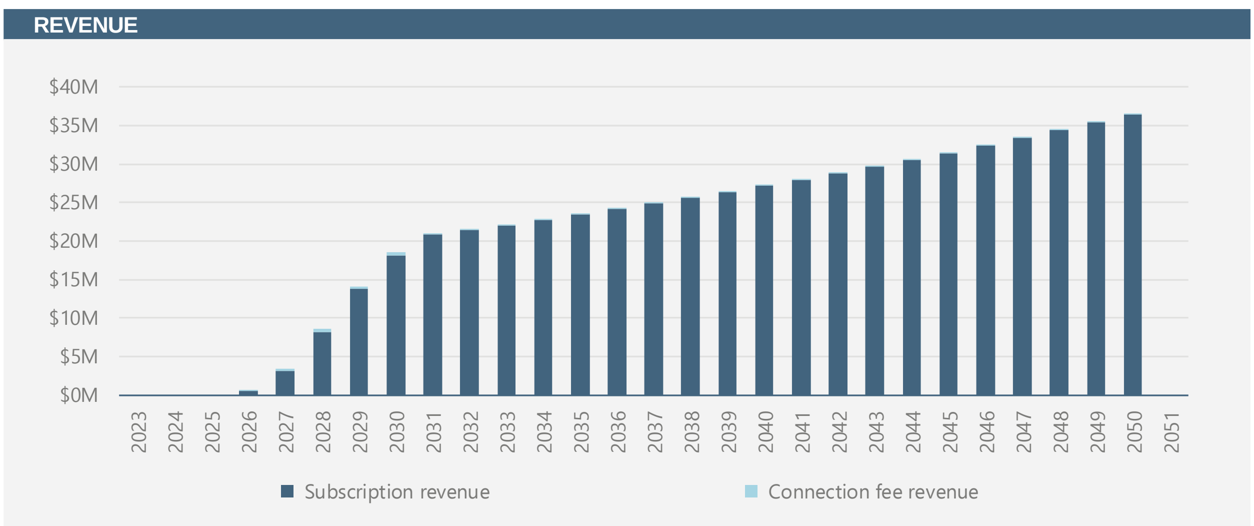
[13] Data reflect a $60 Gig pricing offer on the Metronet website on January 6, 2023, for a residential address in Lexington, KY.

To account for inflation, the ARPU for full paying residential subscribers is assumed to grow at a long-term rate of 3 percent per annum, which is the same rate that is applied to opex growth (see below). Given the potential challenges associated with raising rates for low-income subscribers, no ARPU inflation adjustment is assumed for the low-income subscriber ARPU.

The total subscription revenue is calculated based on the breakdown of low-income residential subscribers and (full paying) residential subscribers and the ARPU for each category. The project team has conservatively assumed that business subscribers amongst the approximately 52,300 passings would pay the same monthly fee as full paying residential subscribers. Furthermore, no enterprise customer revenue is assumed, given the substantial amount of enterprise fiber already existing in the City.

In addition to subscription revenue, the financial model also assumes the ISP will collect a $50 connection fee for each new customer. No additional sources of revenue are included in the financial feasibility analysis. The graph below uses a hypothetical 40 percent take-rate.

Figure 14: Estimated revenue at 40 percent take-rate



Note that total revenue grows rapidly during the ramp up (from 2026 to 2031) when the take-rate is growing to its steady state. Revenue growth beyond that is entirely attributed to the inflation adjustment discussed earlier. The table below illustrates that revenue is affected significantly by the varying breakdown in residential subscribers (low-income and full-paying).

Table 12: Estimated total revenue

Year	Revenue
2030	$18.5M
2040	$27.2M
2050	$36.6M

4.5 Opex

The opex projections were developed through a combination of industry benchmarks and inputs specific to the Cambridge citywide FTTP project. Opex in the financial model consists of three broad categories: 1) labor costs (salary and benefits for the staff required to operate the network), 2) parametric non-labor costs (calculated from specific network parameters), and 3) other non-labor costs (other fixed costs necessary to operate the network).

Labor is the largest opex component, representing 44 percent of the total opex over the forecast period. All opex is escalated at 3 percent for the duration of the forecast period, and there is a steeper ramp-up curve in the early years of network operations, because a significant portion of the opex is determined by the number of network subscribers which reaches a steady state in 2031. A detailed breakdown of the opex line items, benchmarks, and calculations can be found in Appendix A.

Figure 15: Estimated opex

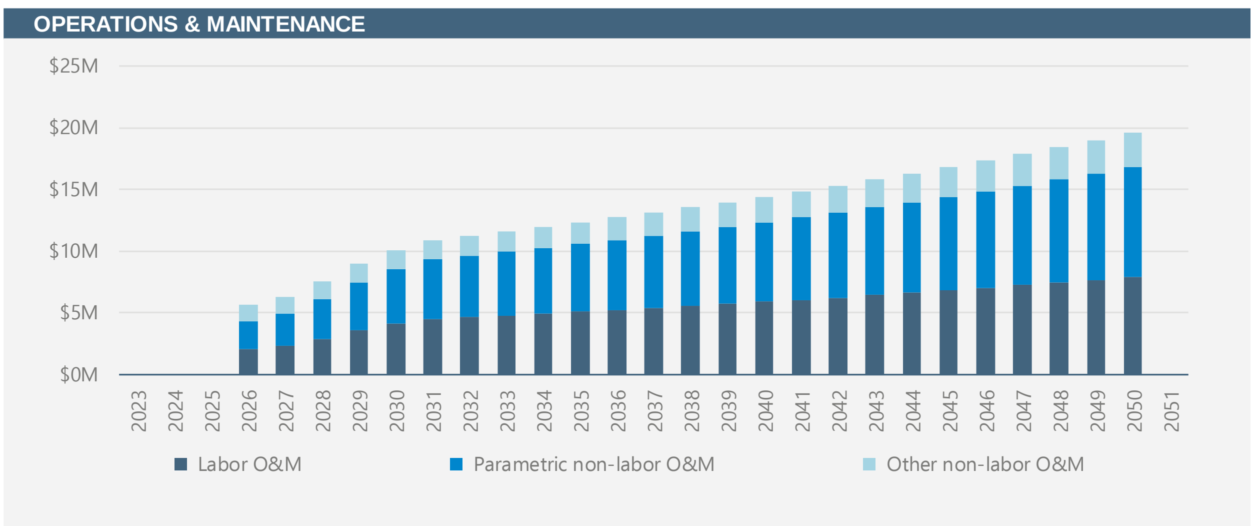


Table 13: Estimated opex

Year	Expenditure
2030	$10.1M
2040	$14.4M
2050	$19.6M

4.6 Project internal rate of return

The project internal rate of return (IRR) is the discount rate that makes the net present value of all cash flows equal to zero in a discounted cash flow analysis, and is a key metric used to calculate the potential profitability of a given investment. As this section set out to determine under what conditions the project can achieve a sufficient project IRR, it is essential to define what would be considered a "sufficient" versus "insufficient" return for an entity making an investment decision in today's environment.

To address that question, we note that the answer depends on the business model of the citywide FTTP project. With the interest rate on 30-year U.S. treasury bonds at almost 4 percent as of late December 2022, for a business model involving purely public financing, a 6 to 8 percent project IRR may be more than sufficiently attractive if the intent is to repay the investment without explicitly valuing all risk that the City would accept under such a model.

In order for the investment to be attractive to a commercial party, they must feel that the returns of the project compensate them for the risk they are taking on for the project. For a business model that is privately financed, the project IRR may need to be closer to the range of 10 to 14 percent to account for the higher weighted-average cost of capital (WACC) if financed with some combination of equity (requiring a 15 to 20 percent return) and debt (at 6 to 8 percent).

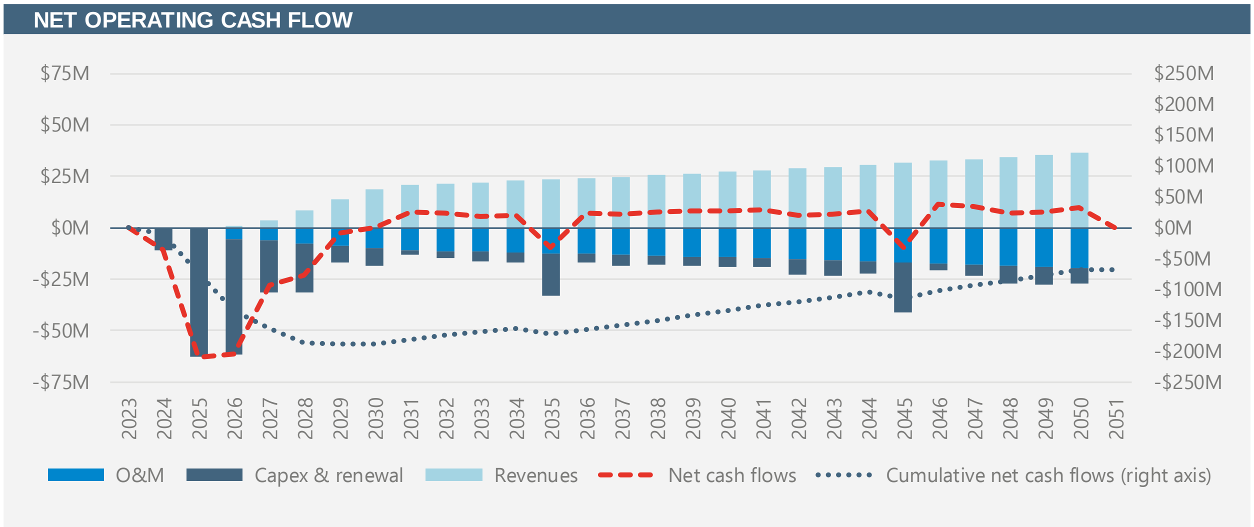
Acknowledging the fact that the required return will depend on the type of financier (i.e., public or private), we use three different target project IRRs in the financial feasibility assessment. A 5 percent project IRR indicates that the project is (barely) feasible. A 10 percent project IRR indicates that the project is feasible and may be profitable. A 15 percent project IRR indicates that the project is feasible and lucrative.

4.7 Financial feasibility analysis results

Using the costs and revenue inputs described above, the financial model can be used to calculate the project IRR, which is determined using the operational cash flows over the forecast period.

The graph below combines the three components of operational cash flow—capex, revenues, and opex—to illustrate the net cash flow that the citywide FTTP project generates in each year from which the project IRR is calculated. Again, a 40 percent take-rate is used for illustrative purposes.

Figure 16: Estimated net operating cash flow and payback period



As can be seen from the graph, the cumulative net cash flow remains negative throughout the life of the project. In other words, at a 40 percent take-rate, the project would not be feasible without any external support. For the project to achieve a 5 percent project IRR, a take-rate of around 70 percent would be required, whereas a hypothetical 100 percent take-rate would yield a project IRR of around 10 percent.

These results help explain why an ISP has not previously overbuilt fiber in Cambridge, because the required take-rates to make overbuilding financially attractive appear unrealistic. In this context, we will next evaluate what the required take-rate would need to be under different upfront capital contribution amounts.

Table 14: Estimated required take-rate with upfront capital contribution for baseline financial feasibility

Take-rate needed to meet target project IRR	Project IRR		
	5%	10%	15%
$100 million in upfront capital contribution	46%	61%	82%
$125 million in upfront capital contribution	40%	51%	65%
$150 million in upfront capital contribution	34%	40%	49%
$175 million in upfront capital contribution	29%	31%	34%
$200 million in upfront capital contribution*	23%	23%	23%

* Required upfront capital contribution amount exceeds overall capex.

As can be seen from the above, an upfront capital contribution can reduce the required take-rate to more attainable levels. For example, a $150 million upfront contribution in combination with a 40 percent take-rate would achieve a project IRR of around 10 percent.

Although capital contributions can improve the project's financial feasibility, an alternative approach would be for the City to provide an ongoing annual operating contribution over the life of the project. For example, to achieve the same 40 percent take-rate requirement for a 10 percent project IRR, the City could decide to instead make annual payment of $16 million per year over the life of the project. Under both structures, risk is reduced by having a reliable ongoing cash flow available to support the network's operations.

We also note that this analysis conservatively ignores the potential for the citywide FTTP network to earn additional revenue by serving enterprise/institutional clients and by leasing backhaul as these markets are already well served in the City. However, there still may be an opportunity to leverage this citywide FTTP network to serve enterprise clients and lease backhaul in Cambridge, which would improve the overall business case. Furthermore, this purely financial analysis does not consider the consumer and other benefits associated with competition, choice, and the superior performance of a citywide FTTP network.

4.8 Sensitivity analysis

The financial feasibility results shown above are based on the key assumptions described in the previous sections. If costs end up being higher and/or revenue lower than assumed, the take-rate would need to be higher to achieve the same project IRR. Similarly, if costs end up being lower and/or revenues higher, the take-rate can be lower to achieve the same project IRR.

As there is significant uncertainty with regards to each of the key assumptions, in this section we will evaluate how sensitive the financial feasibility analysis is to changes in key capex, opex, and ARPU inputs, as well as a longer project forecast horizon. For each sensitivity, we evaluate the impact on the required upfront capital contribution amount for a number of take-rates, ranging from 30 percent to 50 percent.

4.8.1 Capex sensitivity

To run the capex sensitivity, we apply a flat percentage change to the capex contingency that is used to calculate the total estimated capex amount, while keeping all other inputs the same as the baseline financial feasibility analysis. We then examine changes to the upfront capital contribution amount that is required to reach a 10 percent project IRR. The table shows how much the upfront capital contribution amount needs to increase or can drop relative to the baseline analysis (a 30 percent capex contingency) for the following sensitivities: a 10-percentage-point reduction and a 10-percentage-point increase in capex contingency.

Table 15: Required capital contribution amount to meet target project IRR with varying capex contingency

Capex sensitivity Take-rate	Upfront capital contribution amount				
	30%	**35%**	**40%**	**45%**	**50%**
20% capex contingency	$158M	$143M	$130M	$117M	$105M
30% capex contingency (baseline analysis)	$178M	$164M	$151M	$138M	$126M
40% capex contingency	$199M*	$184M	$172M	$159M	$148M

* Required upfront capital contribution amount exceeds overall capex[14]

As can be seen from the table, the network's financial feasibility is quite sensitive to changes in capex. For example, if the capex contingency were to increase by 10 percentage points to 40 percent, the upfront capital contribution would need to increase from $151 million to $172 million to meet a 10 percent project IRR under a 40 percent take-rate. If capex were to be 10 percentage points lower, the required upfront capital contribution falls by $21 million to $130 million.

4.8.2 Opex sensitivity

As with the approach described above for the capex sensitivity, we apply a flat percentage change across all opex categories while keeping all other inputs the same as the baseline financial feasibility analysis. We then examine changes to the upfront capital contribution amount that is required to reach a 10 percent project IRR. The table below compares the required upfront capital contribution amount for the baseline analysis, a 10 percent decrease in opex, a 10 percent increase in opex, and a 20 percent increase in opex.

Table 16: Upfront capital contribution required to meet 10 percent project IRR with changes in opex

Opex assumption relative to baseline	Required upfront capital contribution at various take-rates				
	30%	**35%**	**40%**	**45%**	**50%**
10% decrease in opex	$165M	$151M	$139M	$126M	$114M
Baseline analysis	$178M	$164M	$151M	$138M	$126M
10% increase in opex	$191M*	$177M	$164M	$151M	$139M
20% increase in opex	$205M*	$190M*	$178M	$164M	$153M

* Required upfront capital contribution amount exceeds overall capex

The table above shows that the network's financial feasibility is also sensitive to changes in opex, albeit somewhat less so than to changes in capex. A 20 percent increase in opex would require a $27 million higher upfront capital contribution when compared to the baseline analysis under a

[14] If the required upfront capital subsidy exceeds overall capex, it means that the net present value of revenue is less than the net present value of all future operating costs. As such, the upfront subsidy in such cases is effectively used to partially subsidize the future cost of operations and maintenance.

40 percent take-rate. If opex is 10 percent lower than under the baseline analysis with a 40 percent take-rate, the required upfront capital contribution falls to $139 million.

4.8.3 ARPU sensitivity

The ARPU sensitivity examines the impact on the required upfront contribution amount to reach a 10 percent project IRR if the citywide FTTP project has different ARPU than anticipated in the baseline analysis. Revenue is a product of ARPU and the number of subscribers (including both low income and full paying residential subscribers), which is driven by the take-rate. Our baseline ARPU assumptions are based on a robust set of comparable benchmarks, yet it is critical to understand how variations to the baseline affect the target take-rate. The table below compares the required upfront capital contribution amount under the baseline ARPU assumptions to alternative pricing options for both low-income and full paying residential subscribers.

Table 17: Upfront capital contribution required to meet 10 percent project IRR under various pricing options

Pricing assumption relative to baseline	Upfront capital contribution amount required at various take-rates				
	30%	35%	40%	45%	50%
Low income/full paying: $20/$50	$230M*	$223M*	$217M*	$210M*	$203M*
Low income/full paying: $20/$60	$206M*	$195M*	$185M	$174M	$165M
Low income/full paying: $30/$60	$202M*	$190M	$180M	$169M	$159M
Low income/full paying: $30/$70 (Baseline)	$178M	$164M	$151M	$138M	$126M
Low income/full paying: $30/$80	$156M	$140M	$125M	$110M	$96M
Low income/full paying: $40/$80	$152M	$136M	$121M	$105M	$91M
Low income/full paying: $40/$90	$133M	$114M	$96M	$79M	$62M

* Required upfront capital contribution amount exceeds overall capex

Like capex and opex, ARPU has a material impact on the project's overall financial viability. Increasing ARPU by $10 for both low-income and full paying subscribers reduces the required upfront capital contribution amount from $151 million to $121 million under a 40 percent take-rate. Conversely, decreasing ARPU by $10 raised the required upfront capital contribution amount from $151 million to $185 million.

4.8.4 Project term sensitivity

The final sensitivity we evaluate focuses on the impact to the required upfront capital contribution amount to reach a 10 percent project IRR from changes to the number of years considered in the project's forecast horizon, all else being equal. This is also an important factor to evaluate because, for some potential business models, the City would be structuring a lease or partnership agreement with a private party for a fixed term (e.g., 25 years), and the economics of the operational cash flows change depending on the length of that term. The table below shows the required upfront capital contribution amount for the baseline analysis (25 years), as well as a 20-year operations period and 30-year operations period.

Table 18: Upfront capital contribution required to meet project IRR with varying operating periods

Operating period duration	Upfront capital contribution amount required at various take-rates				
	30%	35%	40%	45%	50%
20-year operations period	$182M*	$169M	$158M	$146M	$136M
25-year operations period (baseline)	$178M	$164M	$151M	$138M	$126M
30-year operations Period	$178M	$162M	$148M	$134M	$121M

* Required upfront capital contribution amount exceeds overall capex

As expected, extending the operations period reduces the required upfront capital contribution amount to achieve a 10 percent project IRR whereas shortening the operations period increased it. This translates to a required upfront capital contribution amount of $148 million for a 30-year operations period vs. $158 million for a 20-year operations period under a 40 percent take-rate.

4.9 Other buildout scenarios

There are alternative buildout scenarios for approaching the project differently, such as constructing the ubiquitous FTTP network all underground, which entails a higher cost, and for building only to MDUs that contain affordable units or are Cambridge Housing Authority (CHA) units. These scenarios all raise per-passing costs and thus significantly impair feasibility. The table below shows the required upfront capital contribution amount for these additional buildout scenarios under a variety of take-rates.

Table 19: Estimated required take-rate with upfront capital contribution for baseline financial feasibility

Alternative buildout scenarios	Upfront capital contribution amount				
Take-rate	30%	35%	40%	45%	50%
Baseline analysis	$178M	$164M	$151M	$138M	$126M
City-wide FTTP network, underground	$305M*	$291M	$279M	$265M	$254M
All affordable housing MDU units	$178M*	$169M*	$159M*	$151M	$142M
Only CHA MDU units	$160M*	$155M*	$149M*	$142M*	$139M*

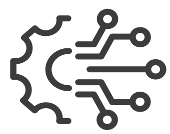
* Required upfront capital contribution amount exceeds overall capex

As can be seen from the above, the underground citywide network scenario and the buildout scenario serving only affordable housing both require more contribution than the citywide network that combines underground and aerial construction. Although the buildout scenario that serves only City-owned affordable houses has a marginally lower contribution requirement compared to the citywide network that combines underground and aerial construction under certain take-rate assumptions, the latter includes approximately 52,300 passings vs. just 22,000 passings for the more limited buildout to City-owned affordable houses.

5 Business models

This section provides an overview of four distinct business models Cambridge might consider for a citywide FTTP network. The models are distinguished by the role of the involved parties across the network's three primary elements: 1) Passive infrastructure, 2) Active infrastructure, and 3) Service provision. All capital and operating costs of the network, as well as all contractual relationships between the City (or another public agency designated by the City) and a private sector entity, fall into one of these three scope elements.

Figure 17: Three elements of the FTTP network

Passive infrastructure	Active infrastructure	Service provision
		
Building and maintaining the dark fiber network	Setting up and operating the network's active electronics	Delivering broadband services to subscribers

The funding and financing associated with each scope element differ across the four business models, as do the allocation of risks, responsibilities, and ownership of assets associated with each scope element. There are key tradeoffs across the business models, particularly between the objectives of retaining local control and transferring risk to the private sector. The business models also differ regarding how the three scope elements are combined into one or several contracts, and how competition is structured in the marketplace, as summarized in the table below. However, in each of the four business models considered, the City (or its designee) would be the owner of the Passive Infrastructure (the dark fiber network).

Table 20: Overview of four business model options

Business model	Passive infrastructure	Active infrastructure	Service provision
1	Publicly funded/financed and maintained	Municipal ISP	
2	Publicly funded/financed and maintained	ISP (one or multiple)	
3	Publicly funded/financed and maintained	Active Infrastructure Contractor	Multiple ISPs / Open Market
4	(Largely) privately funded/financed, privately maintained, and operated		

5.1 Key business model structuring considerations

Regardless of the business model selected, the City should leverage competition to maximize value for taxpayers and subscribers. For this business model discussion, it is helpful to distinguish between the concepts of "competition for" and "competition on" a given scope element. Creating competition *for* a market leads to an efficiently priced asset or service delivered by a single entity. Creating competition *on* a market leads to multiple providers providing an asset or service, competing for market share based on quality of service and/or price. There are various ways to introduce competition for Passive Infrastructure, Active Infrastructure, and Service Delivery, whether through competition for or on the market. How to maximize competition was a key consideration in developing the four business models under consideration.

The four different models also use public and private financing differently. Private financing can be used to achieve material risk transfer ("skin in the game") for long-term infrastructure assets. However, private capital (which we assume will consist of a combination of private equity and debt) also has a significantly higher cost than public borrowing for Cambridge. As such, there is a tradeoff between a more effective risk transfer (i.e., more private capital) and affordability (i.e., more public financing), which also was a key consideration in developing the four business models.

5.2 Business model conclusions and recommendations

Each of the four business models has the potential to meet the City's goals, albeit to varying degrees and with certain tradeoffs, as discussed in Section 5.3. The following key takeaways can help the City decide on which business model to pursue:

- Business Model 1 gives the City the most control, but also requires substantial operational experience, expertise and discipline. Other municipalities that have successfully used this model already had a municipal utility whose operational expertise and resources could be leveraged. As Cambridge does not have a municipal utility or plans to hire dedicated staff for the day-to-day running of a municipal broadband entity, the team recommends against pursuing Business Model 1.

- Business Model 2 leverages the City's access to relatively cheap capital to develop the Passive Infrastructure while transferring most of the operational and commercial risks, including those related to building and financing the Active Infrastructure, to a private partner. The team believes this is a viable and attractive business model for the City, for which the City can apply lessons learned from other municipalities across the US. Whereas this model has been presented as distinct from Business Model 4, many of the best practices regarding P3 project structuring and procurement can also be leveraged for Business Model 2.

- Similar to Business Model 2, Business Model 3 leverages the City's access to relatively low-cost capital to develop Passive Infrastructure. In addition, under Business Model 3, the City also leverages its access to capital to develop Active Infrastructure while transferring most of the operational and commercial risk to private partners. The theoretical advantage of this model lies in the opportunity to have multiple ISPs compete on the municipal network. But there is only a very limited experience with this business model in the United States, and Cambridge is a relatively small market. Given that this model is the least proven, if the City decides to pursue Business Model 3, the team recommends using market sounding to investigate the viability of this approach in Cambridge.
- Business Model 4 increases private sector involvement across all project scope elements to also include developing and financing Passive Infrastructure. Whereas private capital is more expensive than public finance, this premium effectively represents the cost of risk transfer from the City to the private partner. In addition, as the project will likely need a public contribution regardless of the selected business model, some of the project may still be financed using public debt (or available City cash reserves), thus reducing the impact of more expensive private financing on the overall cost of capital. The team believes this is a viable and attractive business model for the City, for which the City can leverage P3 experience from other municipalities across the U.S.

Given the above, the team recommends choosing between Business Models 2 and 4, because we understand that there is likely market interest in either of these approaches; pursuing Business Model 3—which is the least proven—would require the City to define the desired structure of these relationships and conduct a deeper market sounding to identify one or more reliable partners that are willing to participate in this context and have a demonstrated track record of doing so. Section 8 describes in more detail how the City might proceed in developing these business models and procuring a partner.

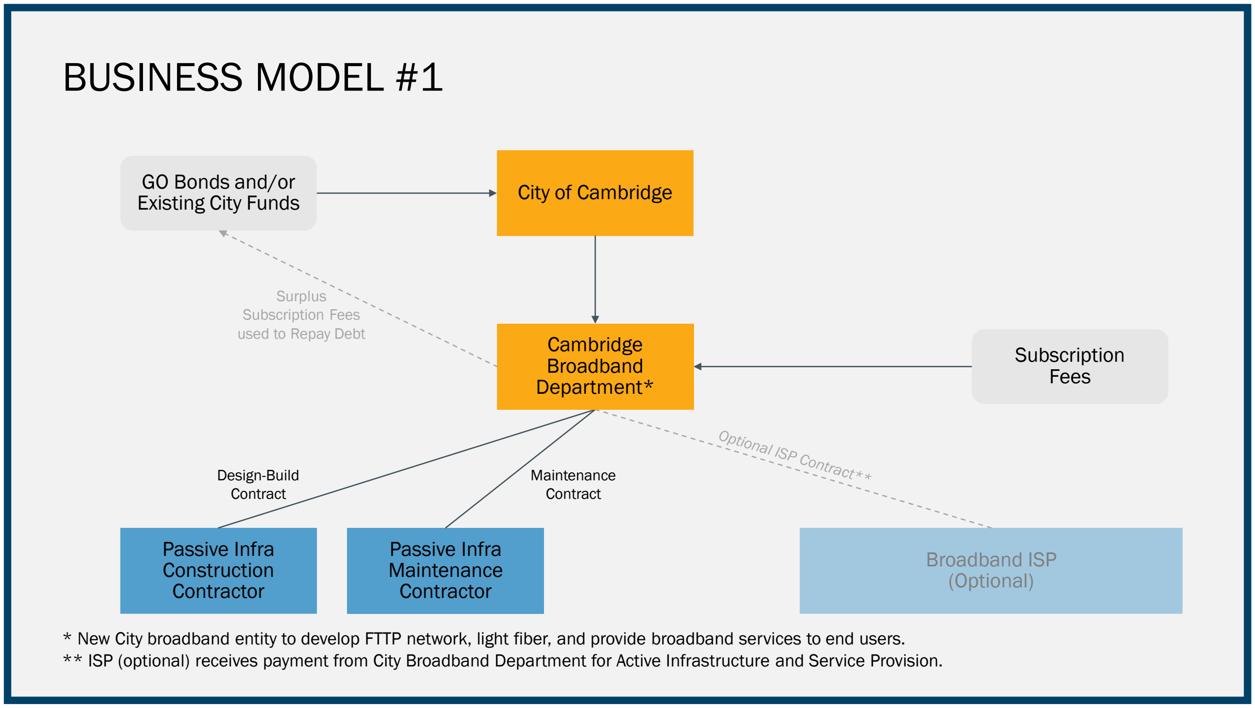
5.3 Overview of business models

The defining characteristics of each of the four business models is described below, along with a diagram illustrating the relationships between the parties involved. In each diagram, the orange boxes represent public sector (City) entities, and the blue boxes represent private sector entities. Arrows represent financial flows (dotted arrows represent potential or contingent financial flows), whereas lines without arrows represent contractual relationships (and dotted lines are optional contract structures or variations to the business model). The descriptions and diagrams are simplified to highlight the key differences between the four business models – there are many additional potential variations within each model that are not displayed or discussed in this report.

5.3.1 Business Model 1

This model is a citywide FTTP network fully funded, owned, and operated by the public sector. Alternatively, the City (or designee) may outsource some of the operating responsibilities, but ultimately remains responsible for the project's success.

Figure 18: Business Model 1



This is the only business model in which the local government agency would have full control over all aspects of the broadband network construction and operations. However, in this model the public sector agency would also fully retain the commercial (revenue) risk and operating risk. In this model, the City would run competitive procurements to select a Design-Build Contractor and a Maintenance Contractor.

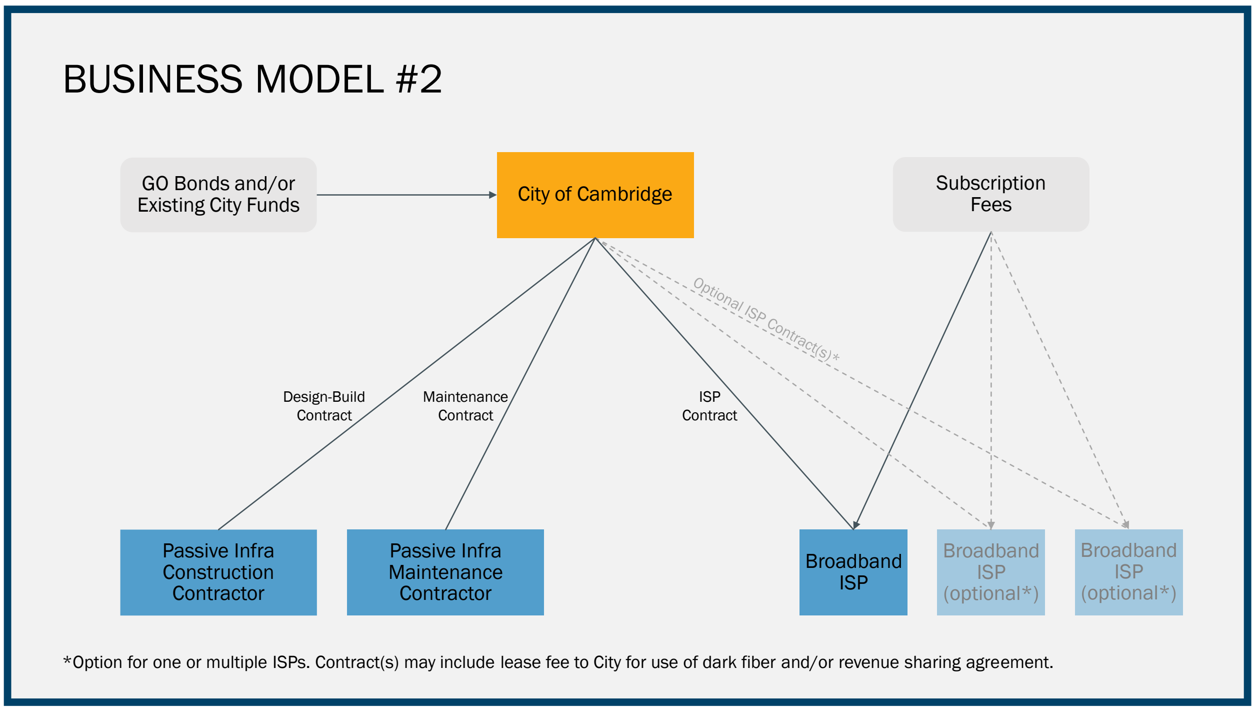
There are multiple examples of this business model across the country, including several in Massachusetts, most of them operated by longstanding municipal electric utilities (called Municipal Light Plants or MLPs). For example, Whip City Fiber is an ISP operated by Westfield Gas & Electric (WG+E), in Westfield, MA. It is also now a regional provider, providing symmetrical 1GB service to homes and businesses in 20 communities in western Massachusetts, most of them rural towns that were previously unserved by high-speed broadband. The local municipalities fund and finance the construction of Passive Infrastructure, and Whip City Fiber provides the active infrastructure and services to end users through Intergovernmental Agreements (IGAs). This case study demonstrates how a municipal utility with existing experience in delivering services to customers can expand into the broadband sector. This example is unusual in that WG+E is serving as ISP for many municipalities.

Please see Appendix E for a discussion of Municipal Light Plants in the context of Cambridge's broadband initiative.

5.3.2 Business Model 2

In this model, the City (or designee) would use public funding and/or financing to contract with a private entity to construct and maintain the Passive Infrastructure. The City would then lease access to the dark fiber network to one or multiple ISPs, who would in turn provide Active Infrastructure and Service Provision. The City (or designee) would have the flexibility to structure a combination of lease fees and revenue sharing agreements to potentially partake in revenue upside scenarios.

Figure 19: Business Model 2



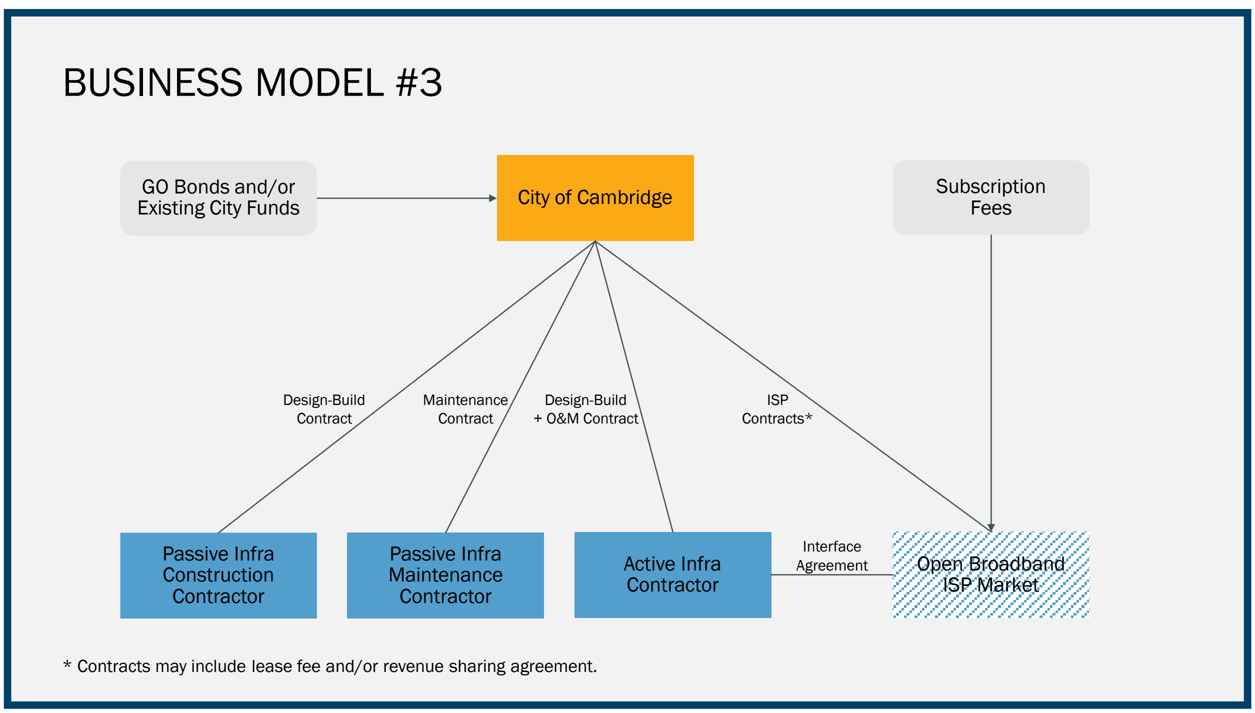
In this model, the private ISP(s) would take the commercial and operating risk and would be incentivized to provide high quality service while compensating the City (or designee) for access to the Passive Infrastructure. As with Business Model 1, the City would seek to minimize cost by running a competitive procurement for the Design-Build and Maintenance contracts for the Passive Infrastructure. The procurement for the ISP(s) will likely be based on a combination of qualitative and quantitative factors, which will need to be determined in the next phase of project development.

An example of a network that largely follows Business Model 2 exists in Colorado Springs, where Ting Internet will provide gigabit Internet service over fiber infrastructure built by Colorado Springs Utilities. In this non-exclusive arrangement, Ting Internet will be the initial anchor tenant on a citywide (not-for-profit) fiber network owned by Colorado Springs Utilities. This model leverages the City's experience in building and managing utilities with Ting's expertise in provisioning and marketing fiber services to customers. Other notable examples of municipal networks delivered under a similar model include Westminster, MD, Huntsville, AL, Breckenridge, CO and Fort Morgan, CO

5.3.3 Business Model 3

In this model, the City (or designee) once again uses public funding and/or financing to contract with a private entity to construct and maintain the Passive Infrastructure. The City also would competitively procure and contract with a separate private entity to design, build, operate and maintain the Active Infrastructure component of the network. The Service Provision element of the network would be provided by multiple ISPs through an open market. Similar to Business Model 2, ISPs would lease access to the Passive and Active Infrastructure from the City, possibly in combination with a revenue share mechanism.

Figure 20: Business Model 3



Under this model, a strict performance requirement regime for the Active Infrastructure contractor would be critical for success, as the Active Infrastructure is essential for network performance and reliability, but the Active Infrastructure would not be exposed to revenue risk.

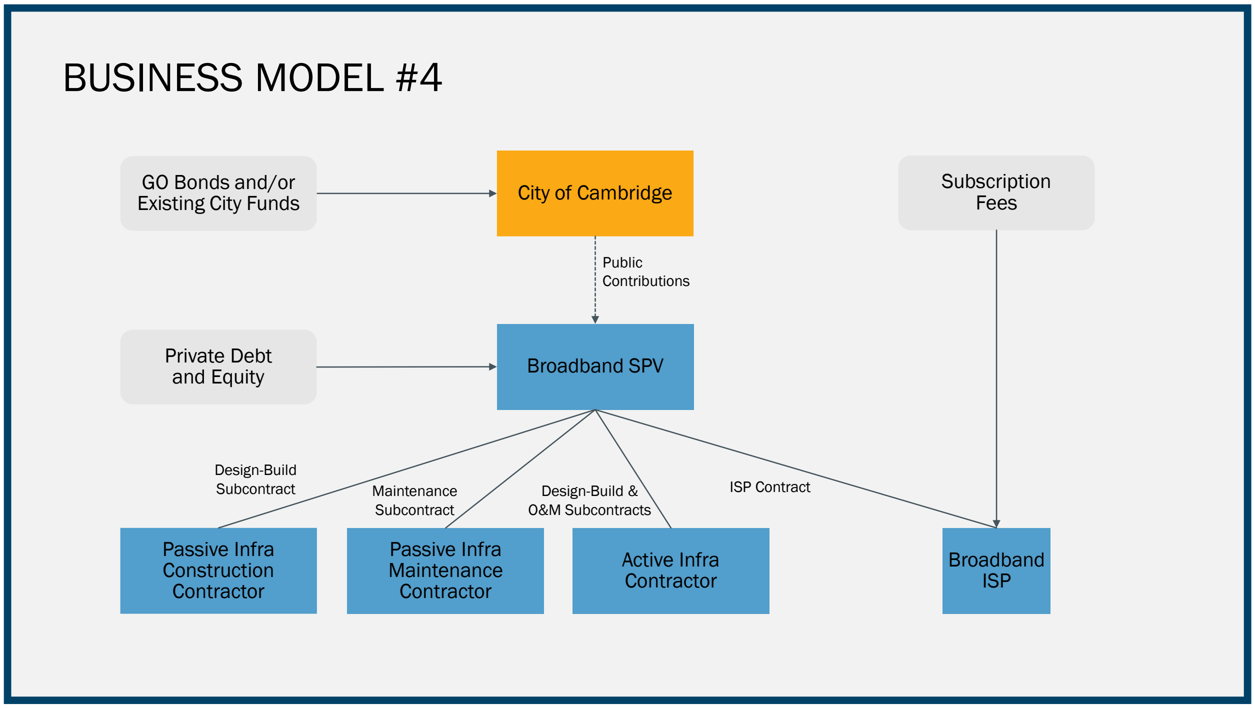
Therefore, the City could employ various mechanisms for ensuring competitive tension and incentivizing performance. In order to realize the theoretical ability of this approach to provide additional choice and competition, the City would need to navigate a high degree of complexity related to structuring contractual performance mechanisms and interface agreements between the Active Infrastructure Contractor and the ISPs. The competition itself will be based mostly on service levels as all ISPs would be using the same underlying Active Infrastructure, removing a key potential differentiator between ISPs. Similar to Business Model 2, the procurement for the ISP(s) will likely be based on a combination of qualitative and quantitative factors to be determined.

The fiber network built in Ammon, ID shares some of the characteristics of this business model. The township of Ammon constructed a dark fiber network, paid for through a combination of federal grants, and funds raised through Local Improvement Districts. Under this model, the network is not built all at once, but is phased with demand; dark fiber is deployed to a neighborhood only when a sufficient percentage of residents “opt in” and agree to be part of a new Local Improvement District. Ammon partnered with EntryPoint Networks to pilot and launch network virtualization software, which includes an online portal allowing four different ISPs to lease bandwidth on the network and offer retail services to customers. This network design is highly automated and allows for new ISPs to be added to the network, and for customers to switch ISPs seamlessly. This general model is prevalent in Sweden. Another similar, notable US example is UTOPIA (UT), although here the active infrastructure is provided by the public sector.

5.3.4 Business Model 4

In this model, the City (or designee) would sign one competitively procured contract with a single private entity that would be responsible for providing all scope elements of the citywide FTTP network including the Passive Infrastructure, Active Infrastructure and Service Provision. The private entity may subcontract for construction and/or maintenance of the Passive and Active Infrastructure. Alternatively, the private entity may self-perform all work. However, under all these alternative contracting structures, the private entity would be the sole entity responsible for the full scope in its contractual obligation toward the City. In this model, some public funding and/or financing contribution could still be used but a significant portion of the financing for all three scope elements will be provided by the private entity and its financiers.

Figure 21: Business Model 4



Under this business model, the City is maximizing its potential for long-term risk transfer through a Project Agreement with a P3 Partner. The P3 Partner has rights of use to the network during the Project Agreement, subject to terms and conditions imposed by the City (e.g., the City can step in if the P3 Partner consistently fails to deliver quality service). The potential downside of this model is the complexity of a P3 procurement and contracting process, and the fact that the higher cost of private financing relative to public financing may not create value for money for an asset with limited lifecycle optimization potential.

An example of Business Model 4 exists in Indiana, where Meridiam will invest more than $90 million to build a ubiquitous fiber network to the cities of Bloomington, Columbus and Shelbyville, IN. Meridiam committed to reaching at least 85 percent of premises, comprising over 70,000 residences and businesses, across the three cities. GigabitNow will be the exclusive ISP for a five-year term, which may be extended to seven years. After the exclusivity period ends, the network will become a full open-access network, open to other ISPs, including local providers, for the lifetime of the network. Meridiam is being provided a $10 million tax break to improve the network's financial viability.

Another example includes Consolidated Communications Holdings Inc (CCI)'s investments in New Hampshire, where CCI has partnered with several rural towns to build out fiber-to-the-premises networks. Under these agreements, the towns will sign 20-year contracts with CCI to run the network (active infrastructure and services), but the towns will retain ownership of the fiber networks. Dublin will finance the construction of the dark fiber with municipal bonds, which will be repaid through subscriber fees charged by CCI, who will also cover the costs in any shortfalls in subscriber revenue needed to cover the town's debt service payments. CCI in exchange for its contribution in financing the network will have sole ISP rights.

5.4 Business model assessment

This section qualitatively compares the four business models by evaluating their alignment with the City's policy goals and examining the allocation of key risks for each.

5.4.1 City objectives

Based on the City's policy goals discussed above, we developed the following criteria to evaluate the various business models proposed against those goals:

- **Public ownership:** Does the business model allow the public sector to retain long-term ownership of (at minimum) the Passive Infrastructure?
- **Local control:** Does the business model allow the City to incorporate key public policy goals into contracts with private partners (e.g., price benchmarking rather than setting rates)?
- **Choice and competition:** Do the business model lend itself to increased choice and competition for subscribers?
- **Minimizing financial risk:** Does the business model serve to minimize the long-term financial risk to the City as the owner of (at minimum) the Passive Infrastructure?

5.4.2 Risk allocation

Risk allocation varies across models. Ultimately, differences in risk allocation arise from the differences in financial and contractual relationships between the involved parties across the four business models. In the table below, "traditional" risk transfer refers to commonly used contractual mechanisms that are used to assign risk and liability for various items in all types of construction and maintenance contracts. Risk transfer from the City to a private sector partner is further enhanced when the partner has invested its own capital in the project and could be adversely financially impacted under poor performance.

Table 21: Risk allocation across business model options

Model	Passive infra	Active infra	Service provision	Construction risk	Maintenance risk	Operating risk	Revenue risk
#1	City	Municipal ISP		Traditional	Traditional	Retained by City	Retained by City
#2	City	Private ISP(s)		Traditional	Traditional	Transferred to ISP[15]	Transferred to ISP
#3	City	Contractor	Open market	Traditional	Traditional	Transferred to Active Infra Contractor and ISPs	Transferred to ISP
#4	Private			Enhanced through long-term private financing	Enhanced through long-term private financing	Transferred to private sector	Transferred to private sector

The diagram above highlights the key distinctions in how the four major categories of risk (construction, maintenance, operating, and revenue risk) are allocated for each business model.

5.4.3 Qualitative assessment

A comparative qualitative evaluation of the four business models against the criteria outlined above show that all business models address the City's goals to varying degrees and come with tradeoffs. The table below contains a summary on how the four business models align with the qualitative criteria.

[15] Maintenance risks associated with Passive Infrastructure is retained by the City.

Table 22: Comparison of business models against policy goals

<table>
<tr><th>Model</th><th>Passive infra</th><th>Active infra</th><th>Service provision</th><th>Public ownership</th><th>Local control</th><th>Choice / competition</th><th>Minimize financial risk</th></tr>
<tr><td>#1</td><td>City</td><td colspan="2">Municipal ISP</td><td>City owns both Passive & Active Infrastructure</td><td>City controls all operational decisions</td><td>One competitor for incumbents</td><td>City retains most financial risk</td></tr>
<tr><td>#2</td><td>City</td><td colspan="2">Private ISP(s)</td><td>City owns Passive Infrastructure</td><td>Private control on pricing & operations, subject to City rules*</td><td>At least one competitor for incumbents</td><td>City retains financial risk of construction; financial risk of operations transferred</td></tr>
<tr><td>#3</td><td>City</td><td>Contractor</td><td>Open market</td><td>Public owns Passive Infrastructure</td><td>Private control on pricing & operations, subject to City rules*</td><td>Likely multiple competitors for incumbents</td><td>City retains financial risk of construction; financial risk of operations transferred</td></tr>
<tr><td>#4</td><td colspan="3">Private</td><td>City owns physical assets, P3 partner has right to commercialize network</td><td>Private control on pricing, operations & fiber network design, subject to City rules/specs*</td><td>One competitor for incumbents</td><td>P3 partner takes substantial financial risk associated with construction & operations</td></tr>
</table>

*Procurement will detail the constraints that apply to the private entity

5.5 Financial implications of the business models

The financial feasibility analysis presented in Section 4 does not include assumptions regarding business models—how the citywide FTTP is funded or financed, or specific contracting and ownership arrangements between the City (or other public agency designated by the City) and private parties. This section evaluates the merits and challenges of each business model from a financial perspective to guide City decision-making around the selection of a preferred business model.

5.5.1 Business Model 1

Under this model, the City would be funding and financing all capex, collecting revenue and paying opex. As such, the baseline financial feasibility analysis described above already reflects the operating cash flows to the City. Therefore, for Business Model 1, a high-level assessment of the financial feasibility of the project conceptually would only require comparing the project IRR to the City's borrowing costs – if the project IRR is higher than the City's borrowing costs, the project should be considered financially feasible (assuming that other debt policy requirements that the City may have also continue to be met).

However, several additional considerations affect how Cambridge should approach this from a policy and financial management perspective, including primarily the type of public financing instrument to use and the impact of additional borrowing on Cambridge's financial flexibility and fiscal health. Through a series of conversations with City officials, the project team determined that public financing for the citywide FTTP project would almost certainly come in the form of general obligation bonds (as opposed to project revenue bonds).

The City maintains a AAA general obligation credit rating and therefore has a relatively low cost of capital compared to other lower-rated municipal borrowers. An estimate of the City's general obligation borrowing cost for a 30-year bond, based on Municipal Market Data, would be 3.50 percent in the market as of this writing (January 9, 2023). Financing the citywide FTTP project through the City's general obligation borrowing program would also require a more comprehensive municipal finance analysis, looking at the citywide FTTP project alongside other key projects in the City's capital improvement plan and evaluating the long-term impact that the issuance of the general obligation bonds would have on the City's credit rating and overall debt capacity and other key financial metrics. This municipal finance analysis falls outside the scope of this study.

As mentioned earlier, under this model, the public sector effectively assumes all risks including, for example, potential cost overruns (to the extent those risks are not transferred through the construction contract), higher than expected opex costs, and lower than expected take-rates and revenue. As the general obligation bonds are repaid from City-wide taxation (primarily property tax) and are not dependent on project revenue, lenders are isolated from the project's risk meaning that the City will need to absorb any losses the project may generate. At the same time, it also means that a commercially successful project would potentially allow the City to generate surplus funds under this model.

5.5.2 Business Model 2

Under this model, the City would be responsible for financing and maintaining the Passive Infrastructure. The City would make the Passive Infrastructure available to one or multiple ISPs in return for an annual lease payment and/or revenue share agreement. The ISP(s) would be responsible for both the Active Infrastructure as well as Service Provision. The project team used the financial model to develop an order of magnitude estimate of a flat annual lease payments that would be necessary to cover the City's investment in and maintenance of the Passive Infrastructure by isolating the investment and maintenance costs associated with the Passive Infrastructure from the remainder of the project.

Assuming the City uses municipal debt with 5 percent interest to finance the capex and associated financing costs, the table below shows the annual lease payment required to cover both debt service and all costs associated with operating and maintaining the Passive Infrastructure. Lease payments are shown for a network with no drops (i.e., drops would be constructed and financed by the ISP), drops to 50 percent of all residential passings, and drops to all residential passings. These estimates do not account for churn (i.e., new drops being required in the future to compensate for subscribers cancelling their subscriptions), but the impacts of churn on the required annual lease payment is relatively modest.

Table 23: Estimated annual lease payment for Passive Infrastructure

Passive infrastructure buildout	Annual lease payment amount
Passive infrastructure: No drops	$14.3M
Passive infrastructure: 50% drops	$15.2M
Passive infrastructure: 100% drops	$16.0M

5.5.3 Business Model 3

Under Business Model 3, the City would be responsible for financing and maintaining the Passive Infrastructure. Furthermore, it would contract an Active Infrastructure Contractor to build and maintain the Active Infrastructure. The City would make both the Passive and Active Infrastructure available to one or multiple ISPs in return for an annual lease payment and/or revenue share agreement. The ISP(s) would be responsible only for Service Provision.

If structured the same way as Business Model 2, the required lease payment under this model would be substantially higher than the order of magnitude estimates provided for Business Model 2, as it would also cover the Active Infrastructure capex investment, requiring frequent equipment renewals, and the Active Infrastructure opex. Given the frequent equipment replacements, any financing would likely need to be structured differently from the long-term financing assumed under Business Model 2.

In Business Model 3, it is likely more efficient to forego debt financing for the Active Infrastructure and instead rely on direct funding of the Active Infrastructure costs. Therefore, the project team did not develop a single all-in annual lease payment for this business model, as the potential financing structure for the Active Infrastructure investments remains unknown.

The table below provides a ballpark estimate of the incremental costs associated with procuring, setting up, and maintaining the Active Infrastructure under Business Model 3. These costs would be in addition to the order of magnitude estimates of the Passive Infrastructure annual lease fee. The table shows the overall nominal annualized expenditure incurred for a network with no drops/CPE (i.e., drops and CPE would be constructed/provided by the ISP), drops/CPE to 50 percent of all residential passings, or drops/CPE to all residential passings. To calculate this annualized expense, total nominal costs are divided by the duration of the operating period (i.e., 25 years). These annualized figures do not account for the potential use of financing.

Table 24: Estimated annual cost for passive infrastructure by buildout scenario

Passive infrastructure buildout	Annual lease payment amount
Passive infrastructure: No drops	$5.8M
Passive infrastructure: 50% drops	$12.9M
Passive infrastructure: 100% drops	$20.1M

The next table combines the order of magnitude estimate of the annual lease fee needed to cover the City's costs associated with the development and maintenance of the Passive Infrastructure with the annualized costs associated with the Active Infrastructure. As mentioned earlier, these figures do not account for any cost of financing that may be used for the Active Infrastructure but give a reasonable understanding of what the combined costs are associated with the Passive and Active Infrastructure.

Table 25: Estimated annual payment for passive and active infrastructure

Passive and active infrastructure buildout	Annual payment amount
Passive and active infrastructure: No drops/CPE	$20.1M
Passive and active infrastructure: 50% drops/CPE	$28.1M
Passive and active infrastructure: 100% drops/CPE	$36.1M

5.5.4 Business Model 4

To determine the financial feasibility for Business Model 4, we would look at the operational cash flows as being fully allocated to the private SPV. Similar to Business Model 1, the baseline financial feasibility analysis already accurately reflects the operational cash flows, only in this case the IRR of those cash flows would need to be compared to the private SPV's cost of capital rather than the City's. The private entity's cost of capital would be substantially higher than the City's borrowing cost for two main reasons.

First, it would likely include a substantial percentage of equity, which is more expensive than debt, making the weighted average cost of capital higher. Second, the debt portion of the private financing would be more expensive than the public general obligation bond financing because the debt would reflect the full commercial risk profile of the project, whereas the City's general obligation bonds would be secured by the full faith and credit and taxing power of the City of Cambridge and therefore significantly less risky.

Although municipal debt financiers are not exposed to the full commercial risk profile of the project under Business Model 1, it is worth remembering that the City would still bear all of those risks, even though they are not pricing into the financing cost. As such, the difference in the cost of capital between Business Model 1 and Business Model 4 is effectively a reflection of the risk transfer from the City to the private sector under Business Model 4.

Acknowledging the higher price of private capital also means that, everything else being equal, the network will need to achieve higher take-rates to meet the higher project IRR requirements associated with private capital.

6 Residential survey

CTC conducted a mail-based survey with significantly expanded scope than what was proposed. To ensure robust participation in an environment where responses to mail surveys have declined in recent years, we conducted a random mailing of 5,000 survey packets, up from the proposed 3,000 surveys. Our goal had been 450 completed and returned surveys; 604 was achieved, resulting in a 95 percent confidence level with a margin of error of 4 percent.

The mail survey was conducted in May and June of 2022 and was intended to gather basic data about the types of services to which residents subscribe and their use of these services. A key goal of the survey was to assess whether existing options are sufficient to meet the needs of households across the area, and whether residents support the City facilitating the entry of a municipal service under a variety of potential operating models.

This report documents the survey process, discusses methodologies, and presents results intended to assist the City in developing strategies to provide internet service to residents. The report highlights some key results for the lower-income cohort (less than $50,000 annual household income) and other demographic groups.

Key findings are here presented thematically in two subsections: broadband access and use, and demand for additional internet service options. These and other findings are presented in greater detail in Appendix B.

6.1 Broadband access and use

The survey found very few gaps in acquisition of residential internet services, but also that lower-income households may be underserved. The following are key findings:

- **Most respondents do have internet access, including both mobile and home internet service.** Almost all (97 percent) respondents said they have a mobile or home internet connection. Specifically, 91 percent have a home internet service subscription, and 83 percent have cellular/mobile telephone service with internet (smartphone). A handful of respondents did not specify type.

- **Most subscribers have one of two internet services in the market area.** Eight in 10 respondents have cable internet service (from Comcast), while 8 percent have fixed wireless service from Starry. Very few respondents have another service. Further detail on internet connection used by respondents is provided in Appendix B.

- **Some lower-income households may be underserved.** Home internet saturation is high across the market area and for all income groups. However, 10 percent of those in lower-income households do not have any internet connection (or did not respond), and 20 percent rely on a smartphone only. Six in 10 lower-income households have both a home internet connection and smartphone, compared with at least eight in 10 of those earning $100,000 or more per year.

- **Connection reliability ranks as the most important internet service aspect among subscribers, followed by connection speed.** Nearly nine in 10 (88 percent) internet subscribers rated reliability as extremely important, and 64 percent said speed is extremely important. The extremely high importance placed on some factors may signal some willingness to switch providers if needs are not being met.

- **Almost all respondents have access to personal computing devices (desktop, laptop, and tablet) in the home.** Just 1 percent of respondents have no device in the household. Fifty-nine percent of households have five or more devices.

6.2 Demand for additional internet service options

Many respondents support having an additional internet service provider in Cambridge, are interested in acquiring service, and are willing to purchase from a new provider at certain price points. The following are key findings:

- **Most respondents said the City of Cambridge needs an additional internet service provider.** Eighty-seven percent of respondents agreed there is a need for an additional ISP in Cambridge, while 12 percent were unsure. Only 1 percent of respondents said there is no need. Furthermore, two-thirds of respondents strongly agreed the City should provide lower-cost broadband service to low-income residents, although they were less likely to agree the City should make funding and construction of City-owned broadband infrastructure a top City spending priority (27 percent strongly agreed).

- **Many respondents would be interested in acquiring services from a new internet service provider in Cambridge.** More than one-half of respondents said they would be very likely (29 percent) or extremely likely (25 percent) to acquire services from a new internet service provider in Cambridge, and another 35 percent would be moderately likely.

- **A new ISP also providing video and phone services is not a significant motivator for most respondents.** Most respondents said this is not at all important (56 percent) or slightly important (13 percent), while another 17 percent said offering video and phone services is moderately important.

- **Many respondents support a new fiber broadband network, even if it is subsidized by the City.** Two-thirds of respondents agreed (26 percent) or strongly agreed (40 percent) the City should facilitate building a fiber broadband network that allows for high-speed service and competition, even if this requires a tax subsidy from the City. In comparison, one-half agreed (20 percent) or strongly agreed (30 percent), but only if it does not require a tax subsidy from the City.

- **Respondents were more likely to agree the City over a private company should manage the fiber broadband network if one were built in Cambridge.** Specifically, 22 percent of respondents agreed, and 40 percent strongly agreed the City should own and maintain the fiber infrastructure. Just one-fifth agreed (10 percent) or strongly agreed (9 percent) a private company should do so.
- **Willingness to purchase 100 Mbps or 1 Gbps internet service from a new provider is relatively high at $30 or $50 per month but drops steeply at higher price points.** About three-fourths respondents who are interested in acquiring service are extremely willing to purchase 100 Mbps internet for $30 per month, and 45 percent are extremely willing at $50 per month. Most (89 percent) respondents are extremely willing to purchase 1 Gbps internet for $30 per month, and 76 percent are extremely willing for $50 per month.
- **Overall, respondents are slightly to moderately willing to pay a temporary fee to help cover construction costs of a new fiber optic broadband network at various price points.** Specifically, 43 percent of respondents are extremely willing to pay a temporary per-household fee for $20 per month for 10 years, dropping to six percent at $60 per month for 10 years.

7 Stakeholder engagement efforts

In addition to the survey, CTC engaged in a range of stakeholder outreach efforts. The efforts included engagement with business groups and individual businesses by means of meetings and online questionnaires distributed by the City and CTC, presentations to the Cambridge City Council in May and November of 2022, and a presentation to Upgrade Cambridge in May.

CTC sought any existing surveys, studies, or action plans developed by business groups or institutions around broadband. Although no such documents emerged from the process, most (but not all) business participants were supportive of City efforts to bring about a new FTTP provider. The effort surfaced complaints about Comcast customer service and pricing, but no reports that service was unavailable or that there was difficulty obtaining a direct fiber connection for businesses needing premium levels of service. (Unlike residences, enterprises in Cambridge have robust options for obtaining enterprise-grade service from fiber providers.)

The major institutions of higher learning—the Massachusetts Institute of Technology and Harvard University—expressed a willingness to continue the conversation and work cooperatively as the effort moves forward to determine areas of potential synergy but did not offer specific commitments at this early stage regarding a specific willingness to contribute to the effort or obtain service from a new network. Further detail on these engagements is provided below.

7.1 Engagement with Harvard and MIT

The project team met with representatives from Harvard and MIT to ask about potential institutional interest in a municipal fiber network, either as potential customers or partners in construction. The representatives expressed support for seeking opportunities to collaborate but said specifics would need to be reviewed and determined in the detailed design and implementation phase.

Neither institution identified specific fiber routes that would be of interest. (Large enterprise customers have existing choices in Cambridge.) But the Harvard representative noted that Harvard facilities are dispersed throughout Cambridge and that the university is continually evaluating connectivity at sites separate from its main campus. MIT's representative noted that MIT would consider an alternative option for leasing dark fiber if it were available.

Both were interested in discussing opportunities to cost share around network construction in cases where it could be mutually beneficial. Both institutions have used City trenching projects in the public right-of-way as an opportunity to install fiber. MIT noted that it was willing to share fiber to provide inter-building connectivity at two complexes managed by the Cambridge Housing Authority—Newtowne Court and Washington Elms.

Both institutions were willing to discuss hosting network equipment, including cabinets, as there is some precedent for installing City infrastructure on their campuses outside of historic areas. Harvard hosts pay stations for the City's updated parking system on its campus, for example, and has worked out easements with the City to build ADA-compliant sidewalks. Similarly, public safety radios have been mounted on certain MIT buildings. Such collaboration could, potentially, extend to City fiber construction.

Representatives were not aware of formal programs by either university to supplement or subsidize home internet service, beyond MIT providing hotspots to some students and a one-time stipend for IT staff to set up home workstations. But the representatives acknowledged the importance of high-quality connectivity in the community at large, including for students and staff. During the pandemic, Harvard received anecdotal reports of connectivity issues, such as cable outages, which impacted remote work. As such, both institutions are supportive of efforts that improve broadband service for the community.

Meeting participants included Sarah Gallop, co-director of the MIT Office of Government and Community Relations; Thomas Lucey, Harvard University's director of community relations for the City of Cambridge; and Marco Gomes, director of infrastructure operations for MIT.

7.2 Engagement with business associations and individual businesses

CTC reached out to business associations including the Kendall Square Association, the Central Square Business Improvement District, Cambridge Local First and the Harvard Square Business Association. This was done by means of meetings, a CTC-drafted questionnaire distributed by the City to a list of businesses and associations, and a CTC online survey distributed to businesses owned by members of the City's BIPOC community. Overall, these efforts provided anecdotes about desire for affordable service and competition with Comcast but in general did not surface new reports or data developed by these organizations.

7.2.1 Meetings with Cambridge Local First and Kendall Square Association

In July 2022, CTC met with representatives from Cambridge Local First, a non-profit association of mostly small, local businesses—an estimated 60 percent are sole proprietorships with one to five employees independent businesses[16]—and the Kendall Square Association, which represents the innovation district in Kendall Square.[17] Meeting attendees included Theodora Skeadas, executive director of Cambridge Local First; B. Kimmerman, Director of Government and Community Relations for the Kendall Square Association; and Kendra Foley, interim co-president of the Kendall Square Association.

Representatives from both organizations said that broadband has not been a priority issues for their members and said they had not gathered data on the matter, noting that other issues for

[16] "Cambridge Local First – Discover your local economy!", Cambridge Local First, https://cambridgelocalfirst.org/.
[17] "About | Kendall Square," Kendall Square, https://kendallsquare.org/about/.

businesses had taken priority due to the Covid pandemic. Members had not reported issues getting high-speed fiber connections to their sites if needed; Cambridge businesses have options for enterprise-grade services from existing fiber providers, in addition to Comcast.

After the initial meeting, Cambridge Local First distributed an online information request developed by CTC that asked business owners about their experiences with local broadband providers. The request received a handful of responses reporting mixed experiences and views. These responses did not produce new insights with respect to the feasibility of municipal broadband in Cambridge.

7.2.2 City-distributed questionnaire sent to business associations

CTC developed questions for businesses associations and the City sent these questions, using an online platform, to several business associations who were encouraged in turn to share it with individual businesses. None of the associations or individual businesses had developed surveys or reports around broadband service, but individual businesses did share some anecdotal feedback about problems with their service. Some of the business associations ranked the relative importance of the City facilitating a fiber network as low; respondents from individual businesses were generally supportive of the idea.

The questionnaire asked the following:

- Have you or your organization ever developed data or produced a report about the adequacy of broadband services and any potential need for new services?
- Short of a formal survey or report, what feedback have you heard from businesses about any unmet need for or problems with broadband services, and how has this feedback been received and handled?
- Have you heard from any businesses—including ones seeking to potentially locate in Cambridge—about problems with getting a direct fiber connection from any provider?
- Have you or your association developed an opinion about the need among businesses for an additional service provider in Cambridge to compete widely with Comcast, and the likely demand for such service?
- Thinking about the range of possible efforts the City could undertake to support Cambridge businesses, how would you rank the relative importance of the City facilitating citywide fiber network to compete with Comcast and other providers?
- Please provide any additional opinions, comments, or information you would like to share.

The questionnaire received eight responses, one of which was from Cambridge Local First (covered above). The other seven responses are summarized below.

Business organizations

Leaders at the Kendall Square Association, Central Square Business Improvement District, and Harvard Square Business Association submitted responses.

All three organizations indicated that they had not collected data or received feedback from members about unmet need for or problems with broadband services. Similarly, none reported that they were aware of any businesses experiencing issues getting a direct fiber connection from a provider. The Kendall Square Association, did however, note that "there has been concern from Kendall businesses about the lack of internet access in abutting neighborhoods for low-income residents."

While none of these organizations indicated that they had developed an opinion about the need for an additional provider to serve businesses, respondents voiced mixed opinions about the importance of the City facilitating a citywide fiber network to compete with Comcast and other providers.

- The Kendall Square Association representative indicated that "the issue is pretty low on the list," while the Central Square Business Improvement District representative ranked it "very high."
- The Harvard Square Business Association representative rated the issue of "very low" importance, continuing: "The city should allow the experts (Verizon, Crown Castle, Comcast etc.) to provide the service...and not get in the business of competing with them. Fix the roads, fix the schools, fix the water mains, and build more affordable housing. Stay with what you do best."

Local businesses

Four local businesses—Hilton Realty, Avest Home Repair and Painting, Cambridge Spirits, and Girls Chronically Rock—also responded to the survey.

Three out of these four businesses had not collected data around the adequacy of broadband services, with the remaining respondent "unsure." When asked about any feedback they had received from local businesses, however, respondents were generally supportive of efforts by the City to bring in a new provider.

- Meichelle Ferguson of Hilton Realty noted that "better service would definitely be appreciated," and Norman Daoust of Avest Home Repair and Painting said that "I am interested in municipal broadband."

- Charlie Marquardt from Cambridge Spirits noted that the business' Kendall Square location utilizes Verizon Fios service and continued, "I have customers comment on how much faster my payment processing is from other stores outside of Kendall Square. When customers mention this, it causes me concern that ability to have good broadband or not can affect businesses. In a City as technologically advanced as Cambridge, this should not be the case. This causes me great concern for the disparities that could, and probably do, [exist] in broadband access across the City and its impact on equity."
- Keisha Greaves of Girls Chronically Rock reported experiencing "spotty" service, resulting in dropped video calls.

All four indicated that they supported the idea of the City facilitating a citywide fiber network.

- Charlie Marquardt from Cambridge Spirits responded: "I think having an alternative to a monopolistic provider is important. … [W]e need more than just the one option of Comcast."
- Meichelle Ferguson of Hilton Realty noted that "additional options often equate [to] the possibility of better service."

7.2.3 Engagement with BIPOC-owned businesses

CTC also reached out to small businesses owned by members of the City's BIPOC community. The 20 respondents indicated a desire for affordable service and competition with Comcast. The following questions were included on the questionnaire:

- Have you or your organization ever developed data or produced a report about the adequacy of broadband services and any potential need for new services?
- Short of a formal survey or report, what feedback have you heard from businesses about any unmet need for or problems with broadband services, and how has this feedback been received and handled?
- Have you or your association developed an opinion about the need among businesses for an additional service provider in Cambridge to compete widely with Comcast, and the likely demand for such service?
- Thinking about the range of possible efforts the City could undertake to support Cambridge businesses, how would you rank the relative importance of the City facilitating a citywide fiber network to compete with Comcast and other providers?
- Please describe any problems your business has had with Comcast (or other provider) broadband service – whether it was cost, reliability, or other matter – and describe the provider's level of responsiveness. Please be specific.

- Please provide any additional opinions, comment, or information you would like to share.

Though no respondents shared data or reports, they all voiced strong support for the City's efforts in this area.

Jason Doo of the business Wusong Road wrote: "Since there is only one provider they force you into tiers of service that balloon in price and always seem either: 1) under your needs or 2) way above your needs as a business."

Suzanne Watzman of Tamaryn Design wrote: "We are amazed that Cambridge, center of tech development, has given Comcast as a monopoly. They deliver (or do not) very poor service, poor, untrained customer support people, etc. I cannot say enough about how bad this is for business."

Many respondents highlighted the problem of affordability. Selena Tan of O Positive Coaching and HR Services, wrote: "I have had to pay a high rate for Comcast business internet service: $130/mo. for 250 Mbps, and there have been consistent disruptions, requirement to lease equipment even though my prior internet modem was more than adequate, according to the installer, and the requirement to extend contract in 3-year increments to have the best price."

Damien Mahaffey, of Mahaffey Real Estate, wrote: "Comcast is expensive in general. I do think competition would yield the best rates for both businesses and residents within the City of Cambridge."

Asked about the relative importance of this matter for the City to intervene, respondents provided the following feedback:

- Harold Gilmer of Elite Barbershop wrote: "Competition is always good for competitive pricing."
- Nephatiliem D. McCrary of Great Eastern Trading Co. wrote: "The importance is HIGH in our opinion."
- Bernard Hicks of Nu Image Barbershop wrote: "It's very important and I would rank it high on your list for Cambridge businesses."
- Deb Colburn of NOMAD stated, "There should definitely be competition for broadband services in Cambridge."
- Jason Doo of Wusong Road said, "Everyone needs internet, for education, for entertainment, and for conducting day-to-day business. … Providing a free (to those who need it) or a competitively priced internet would help nearly everyone."

7.3 Engagement with Upgrade Cambridge

In the spring of 2022 CTC met with and provided a presentation about the study process to Upgrade Cambridge, the organization that advocates for municipal broadband for all residents and businesses in the city. Upgrade Cambridge provided feedback that it wished for the City to do extensive outreach and community engagement. As one idea, members said it might be useful to ask local institutions and tech/biotech businesses to survey their own employees and other members of their communities who live in Cambridge as a way of finding clusters of potential customers and engaging these institutions and businesses in discussions about whether they reimburse employees for home broadband and under what conditions they might use their reimbursement policies to incentivize the use of municipal broadband.

CTC's residential survey, mailed to 5,000 residents, was underway at the time of the meeting. A random survey is the most reliable approach when trying to capture accurate data about community viewpoints. As it turned out, the survey found strong support for City efforts toward bringing in a FTTP provider, and even a willingness to subsidize. Although the consulting team did not ask major employers to conduct surveys of some employees on the City's behalf about broadband alone, the team did incorporate Upgrade Cambridge's feedback by asking several business organizations as well as MIT and Harvard whether they had ever conducted surveys on this topic or otherwise developed data on the matter. The results of these efforts are described above.

Upgrade Cambridge also offered the opinion that formation of a municipal lighting plant (MLP) might be a good idea even if the City were only to build dark fiber for leasing. Many municipalities have indeed used MLPs for broadband purposes. Appendix E: Massachusetts Municipal Light Plants provides perspective on the topic and recommend continuing consultation with legal counsel about MLP formation.

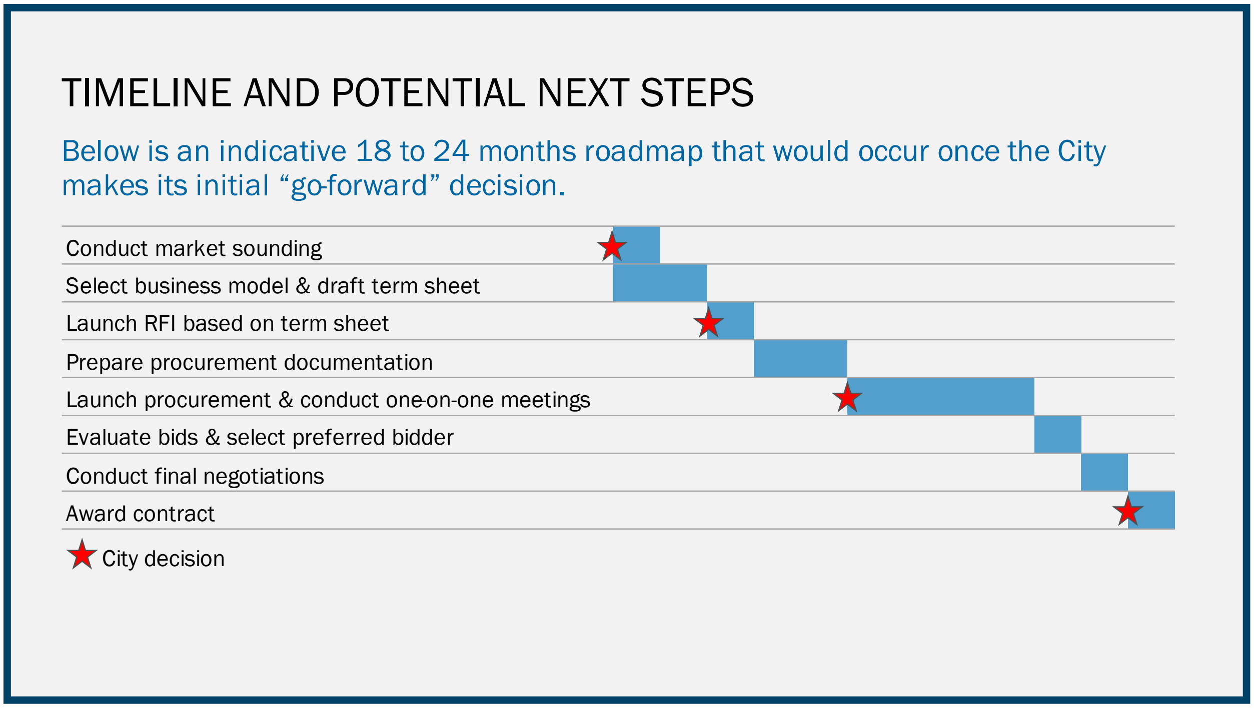
8 Indicative roadmap and next steps

This section introduces an indicative roadmap for the City as it considers next steps and a potential procurement for one or more private sector partners for the citywide FTTP project, incorporating experience and best practices from other P3 procurements. The ultimate procurement process will depend on the selected business model as well as the type of procurement, as described below. This indicative roadmap may need to be modified to be in accordance with the governing law in Massachusetts.

As noted in the Executive Summary, this process would also provide critical data on the potential magnitude of a City contribution. The present study's financial feasibility analysis determines the required City contribution to reach a 10 percent IRR, with assumptions that include a 40 percent take-rate, regardless of how the project is financed or structured contractually. In a partnership model, the eventual partner might be able to realize economies of scale by expanding existing operations or it might have access to existing fiber or other network assets already present in Cambridge. Competition might even emerge among potential partners responding to a City procurement. These kinds of business factors would also influence the magnitude of any required financial contribution from the City—potentially to the City's benefit.

Table 26: Potential next steps (18 to 24 months) provides an indicative 18- to 24-month roadmap that gives the City an idea of key activities and decision points from the time City formally decides to pursue this project.

Table 26: Potential next steps (18 to 24 months)



8.1 Market sounding/RFI

As described in Section 4 on the financial feasibility of the network, the project team's analysis is meant to provide an indication of the attractiveness of the network from a commercial perspective. Should the City decide to move forward with the project, it is critical for the City to engage with the universe of potential commercial partners to validate the commercial feasibility of the project. Furthermore, feedback from the industry on the potential business models the City is considering will be invaluable for refining the models and seeking to address any flaws.

This would not require the City to make a final decision on its own preferred business model for the project prior to these discussions. Instead, the market sounding would provide a set of critical additional data points to validate the City's potential preferences for one model or another, gauge the commercial risk tolerance of prospective bidders, and confirm that the project would be a commercially attractive opportunity with a given business model and buildout scope. The conversations also would allow the City an important opportunity to answer prospective bidder questions about the City's objectives, cost analysis and commitment to the project.

Employing the informal market sounding approach also does not foreclose the possibility of launching a formal RFI process shortly afterwards (see below) if the City feels like it would be helpful to obtain further clarity on key questions in writing from market participants and/or to further advertise the possibility of a forthcoming procurement opportunity. An RFI would likely be recommended after the City has formed a relatively clear idea for its preferred business model and can clearly communicate the project structure to the market. The applicability of an RFI would need to be conducted under the governing law in Massachusetts.

Although no formal documentation needs to be provided as part of the early market sounding, the project team recommends developing a project brief that lays out the goals and key terms / principles guiding the proposed partnership for potential commercial partners to comment on. The project brief would cover the following key topics:

- Policy goals
- High-level project scope and overview, including the geographic scope of the network, basic responsibilities associated with the three main scope elements, preliminary funding and financing approach, and expected contract term
- Ownership structure of project assets
- Parameters related to pricing for broadband subscribers

The project team recommends developing a detailed term sheet based on the City's preferred business model and the feedback received from potential partners in order to advance the project, as discussed below.

8.2 Term sheet

Leveraging its analytical work on business model structuring, the financial feasibility analysis, and feedback from potential partners through the market sounding on potential business models, the project team recommends the City to prepare a detailed term sheet that describes the key terms of the preferred business model.

Whereas the term sheet would not be intended to define every single term of the proposed partnership in detail, it would communicate to interested parties what to expect in terms of general structure and overall commercial terms. The term sheet would be used to formally confirm market interest in the network and solicit feedback on specific terms. In addition, developing a term sheet is a great tool to address any internal confusion that may exist about the exact terms of the proposed transaction and is useful to market the project externally.

8.3 RFI and industry outreach

Using the term sheet, the project team recommends formally engaging with potentially interested parties to gauge their interest and solicit specific feedback on the various terms in the term sheet. This could potentially be structured as a request for information (RFI) in combination with more general industry outreach to market the project. The intent of soliciting feedback would not be to "give in" to all requests for modifications but to identify items that could become potential deal breakers for bidders and/or their financiers (if private financing is pursued). Based on the RFI and industry outreach feedback, the term sheet would be adjusted as appropriate.

Besides potentially contributing monetarily to the network, the City should also consider adopting policies that lower the cost of developing a fiber network. In particular, the City should evaluate its permitting rules and processes to look for opportunities to streamline them and make executing those responsibilities easier and ultimately cheaper. The City could use discussions with industry to refine these strategies and discuss how they might affect the business case and contractual arrangements.

Uncertainty around construction costs is likely an important contributing factor for why a fiber overbuilder has not already deployed an FTTP network in Cambridge. Without a detailed cost estimate commissioned by the City and a commitment from the City to streamline the permitting process, a potential overbuilder was likely factoring in a significant construction risk premium into its evaluation of potential returns. The cost estimate summarized in this report, and a clear commitment from the City to support a citywide FTTP project, should help to significantly de-risk the project for potential private partners, ultimately reducing the level of public contribution required.

The RFI process and industry outreach, if pursued, allows the City to clearly communicate the progress made to date as well as its commitment to the project.

8.4 Procurement strategy

From the prior phases of market engagement, the City will have gained valuable insight regarding the market's preferences, as well as its own preferences, for an overall procurement structure, including whether to pursue a traditional two-step (RFQ/RFP) procurement process or instead follow a Project Development Agreement (PDA) process, subject to the governing law in Massachusetts. The latter can be particularly effective in cases where it is difficult to define the project scope clearly upfront, which may not be relevant for Cambridge if there is a clear consensus on what the project's scope should be.

8.5 Draft procurement documentation and launch procurement

After developing the procurement strategy, the City would next draft the procurement documentation (RFQ/RFP) and Project Agreement, subject to the governing law in Massachusetts. Key elements for the City to focus on during this phase are the financial evaluation criteria, the financial proposal requirements, any interest rate protection mechanism (if applicable), and financial close security (if applicable). It is also critical for the City to develop a transparent bid evaluation mechanism, reflecting the City's key policy objectives, stimulating competition, and allowing for bidders' creativity. The evaluation methodology should be rigorously stress tested from the perspective of bidders and financiers to mitigate the risk of unintended bidding behavior.

One of the most important exhibits to the procurement documentation will be the draft Project Agreement. This document will reflect the risk allocation between the City and its private partners, as informed by the City's objectives and the market outreach, and other key commercial issues. The draft Project Agreement will also contain, as applicable to the selected business model, the details of any public contribution provisions, revenue sharing mechanisms, performance deductions mechanisms, interest rate and credit spread risk sharing approach, and sections on refinancing and compensation for termination.

As a result of the market engagement, the City will likely have a good understanding of the terms and conditions that bidders will focus on, helping it develop a balanced structure that protects the City's interests while ensuring the transaction is financially viable and sufficiently attractive for potential commercial partners.

8.6 Procurement evaluation, negotiations, and closing

In terms of evaluating financial proposals, the project team recommends the City to review the overall financing structure, proposed financing terms, and financial models for:

1. Responsiveness (i.e., confirm whether the financial proposal meets the requirements of the solicitation documents),
2. Robustness (i.e., confirm whether the proposed plan of finance is credible and contains sufficient redundancy so that we can be confident that the bidder will be able to execute it as proposed, for example in terms of the amount of debt and equity committed from investors and financiers), and
3. City financial impact (i.e., evaluate what is the expected cost of the proposal to the City over the life of the Project). In parallel to the financial evaluation, the City will review the proposed technical approach to confirm that it meets its policy goals.

The City's overall procurement approach should be geared toward minimizing final negotiations, as potential partners will have had ample opportunity to comment on the term sheet and raise any outstanding issues during the one-on-one meetings in the procurement process. To the extent that private financing is part of the selected deal structure, the burden of the closing process largely lies with the preferred bidder.

Appendix A: Forecasted operating expenditure

The opex forecast included in the financial feasibility analysis was developed through a combination of industry benchmarks and inputs specific to the Cambridge citywide FTTP project. This appendix breaks down the inputs, assumptions and calculations used in the development of the opex forecast.

Opex in the financial model consists of three categories, broken down further below into discrete line items: 1) Labor costs, 2) parametric non-labor costs, and 3) other non-labor costs.

Labor costs

Labor costs consist of seven fixed staffing categories and three variable staffing categories. The inputs for the fixed and variable staffing levels are based on the project team's industry expertise and comparable projects. Fixed staffing levels remain the same from the start of operations in Year 2026 onwards whereas variable staffing levels ramp up until Year 2031 and remain steady thereafter.

Table 27: Fixed staff FTEs

Fixed staff category	Number of FTEs (year 2026 onward)
Integrity Manager	1
GIS Analyst	2
Senior IT Specialist	1
IT Specialist	3
Customer Account Rep I	3
Account Clerk I	1
Field Services Technician	1
Total Fixed Staff	12

Table 28: Variable staff FTEs

Variable staff category	Number of FTEs (year 2031 onward)	Notes on variability
Customer Account Rep I	15	Based on # subscribers
Customer Account Rep II	6	Based on # subscribers
Account Clerk II	6	Based on # subscribers
Total Variable Staff (Y2031)	*27*	

The number of FTEs for each staff category is multiplied by the salary cost for each category to arrive at total labor costs. In addition to the salary costs, it is assumed that there is an additional

40 percent labor cost for staff benefits. The table below shows the salary costs for each staffing category with and without the 40 percent additional benefits.

Table 29: Salary costs

Staff category	Salary ($2022) per year without benefits	Labor cost ($2022) per year inclusive of benefits
Integrity Manager	$154,000	$215,000
GIS Analyst	$94,000	$132,000
Senior IT Specialist	$120,000	$168,000
IT Specialist	$102,000	$143,000
Customer Account Rep I	$59,000	$83,000
Customer Account Rep II	$68,000	$95,000
Field Services Technician	$101,000	$141,000
Account Clerk I	$59,000	$83,000
Account Clerk II	$68,000	$95,000

All salaries are projected to grow at an annual rate of 3 percent.

Parametric non-labor costs

Parametric non-labor costs are opex items that are calculated based on specific network parameters. The parametric input values are based on the project team's industry expertise and comparable projects. The table below summarizes these opex line items.

Table 30: Parametric non-labor opex costs

Parametric non-labor opex category	Opex per unit ($2022)
Locates & ticket processing	$550 / month / mile outside plant
Core network equipment maintenance	15% of core network equipment cost / year
CPE maintenance	5% of CPE cost / year
Education & training	2% total labor cost / year
Customer billing	$0.20 / month / subscriber
Bad debt allowance	0.50% of total revenue
Commodity internet/bandwidth	$500 / Gbps / month
Pole attachment	$20 / pole /year

All parametric non-labor opex categories are projected to grow at an annual rate of 3 percent.

Other non-labor costs

Other non-labor costs are annual fixed costs and include all remaining opex items. These estimates are also based on the project team's industry expertise and comparable projects but have been modified where appropriate to meet the specific circumstances of the City.

Table 31: Other non-labor opex costs

Other non-labor opex category	Opex per year ($2022)
Insurance	$400,000
Utilities	$200,000
Office expense	$50,000
Contingency	$200,000
Legal	$50,000
Consulting	$75,000
Marketing	$250,000

All other non-labor opex categories are projected to grow at an annual rate of 3 percent.

Appendix B: Residential survey report

This appendix describes the residential survey conducted in May and June 2022.

Survey process

As part of an effort to evaluate and improve high-speed communications services in the area, the City of Cambridge conducted a mail survey of residences in May and June 2022. The survey captured information about residents' current communications services, satisfaction with those services, willingness to purchase service from a new provider, and opinions regarding the role of the City regarding internet access and service. A copy of the survey instrument is included in Appendix D.

The City acquired the services of CTC to help assess internet access and evaluate options to improve service. CTC coordinated and managed the survey project, including development of the questionnaire, sample selection, mailing and data entry coordination, survey data analysis, and reporting of results.

In the project planning phase, the City and CTC discussed the primary survey objectives, the timing of the survey and data needs, and options for the survey process. The project scope, timeline, and responsibilities were developed based on those discussions.

CTC developed the draft survey instrument based on the project objectives and provided it to City staff for review and comment. City staff provided revisions and approved the final questionnaire. CTC coordinated printing, mailing, and data entry efforts, then performed all data coding and cleaning, statistical analyses, response summaries, and reporting of results.

Survey mailing and response

A total of 5,000 survey packets were mailed first-class in May 2022 to a random selection of residential households with a goal of receiving at least 400 valid responses. The sample was stratified by household income, with 3,000 survey packets sent to lower-income households (earning under $50,000 per year) and 2,000 survey packets sent to higher-income households (earning $50,000 or more per year). Recipients were provided with a postage-paid business reply mail envelope in which to return the completed questionnaire by June 17, 2022. Responses were accepted after the reply-by date, through July 1, 2022.

A total of 604 useable questionnaires were received by the date of analysis, providing a gross response rate of 12.1 percent. The margin of error for aggregate results at the 95 percent confidence level for 604 responses is ±4.0 percent. That is, for questions with valid responses from all survey respondents, one would be 95 percent confident (19 times in 20) that the survey responses lie within ±4.0 percent of the target population as a whole.

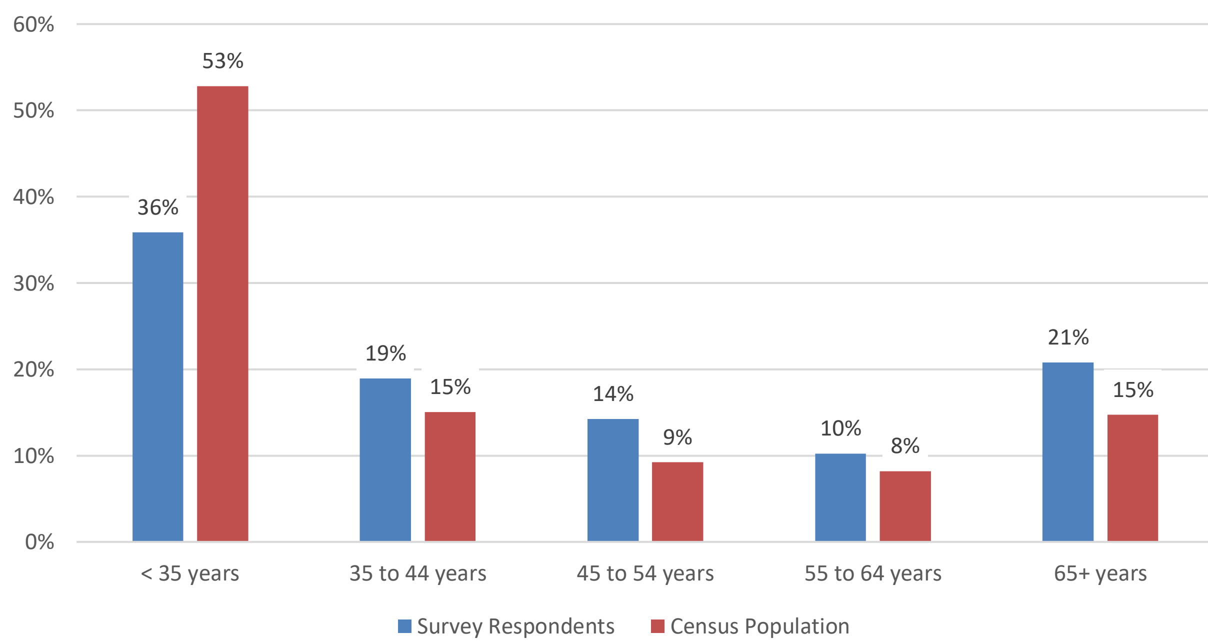
Data analysis

The survey responses were entered into SPSS[18] software and the entries were coded and labeled. SPSS databases were formatted, cleaned, and verified prior to the data analysis. The survey data was evaluated using techniques in SPSS including frequency tables, cross-tabulations, and means functions. Statistically significant differences between subgroups of response categories are highlighted and discussed where relevant.

The survey responses were weighted based on the age of the respondent, household income, and race/ethnicity. Because older individuals and White/Caucasian, non-Hispanic individuals were more likely to respond, the weighting corrects for the potential bias based on the age and race/ethnicity of the respondent. In this manner, the results more closely reflect the opinions of the City's adult population.

Figure 22 summarize the sample and population distributions by age.

Figure 22: Age of respondents and adult population



The following sections summarize the survey findings. The results presented in this report are based on analysis of information provided by 604 respondents from an estimated 47,449 residences in the City of Cambridge. Results are representative of the set of households with a confidence interval of ±4.0 percent at the aggregate level.

[18] Statistical Package for the Social Sciences (http://www-01.ibm.com/software/analytics/spss/)

Unless otherwise indicated, the percentages reported are based on the "valid" responses from those who provided a definite answer and do not reflect individuals who said "don't know" or otherwise did not supply an answer because the question did not apply to them. Key statistically significant results ($p \leq 0.05$) are noted where appropriate.

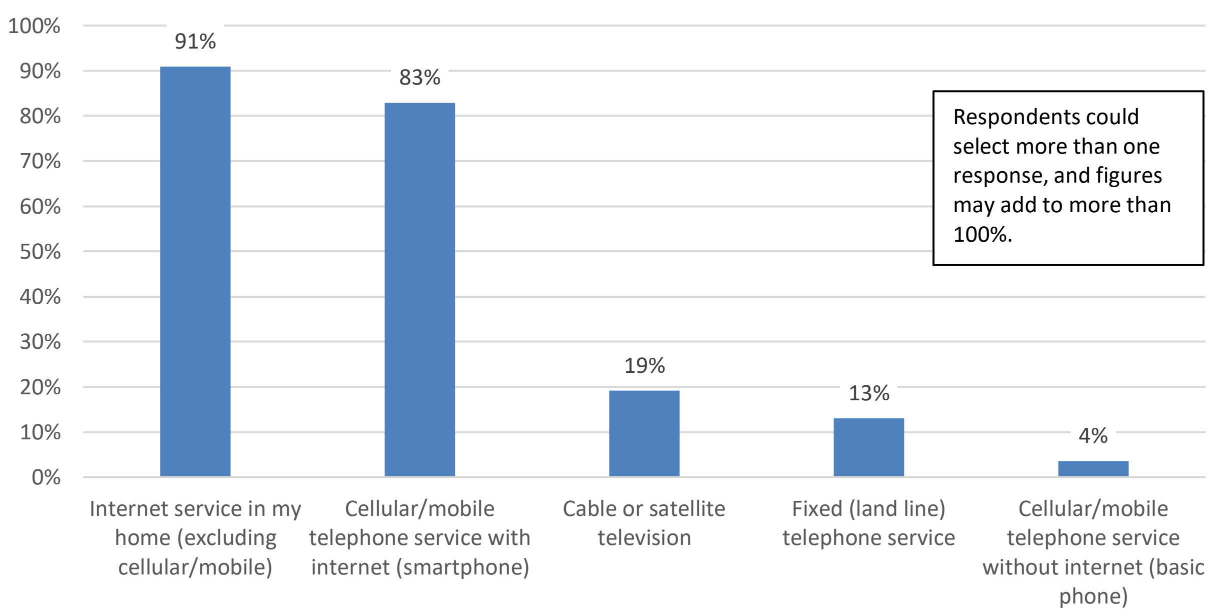
Home internet connection and use

Respondents were asked about communications services, internet connection types and providers, and satisfaction and importance of features related to internet service. This information provides valuable insight into residents' need for various internet and related communications services.

Communications services

Respondents provided information about the communications services currently purchased for their household. As illustrated in Figure 23, most households have internet access, including 91 percent with internet service in the home and 83 percent with cellular/mobile telephone service with internet. Just 19 percent of households have cable or satellite television, 13 percent have landline telephone service, and 4 percent have cellular/mobile telephone service without internet.

Figure 23: Communication services purchased



Respondents ages 65+ were less likely than younger respondents to report having internet service in the home or cellular/mobile telephone with internet, and they are more likely to have landline telephone service or cable/satellite television (see Figure 24).

Figure 24: Services purchased by respondent age

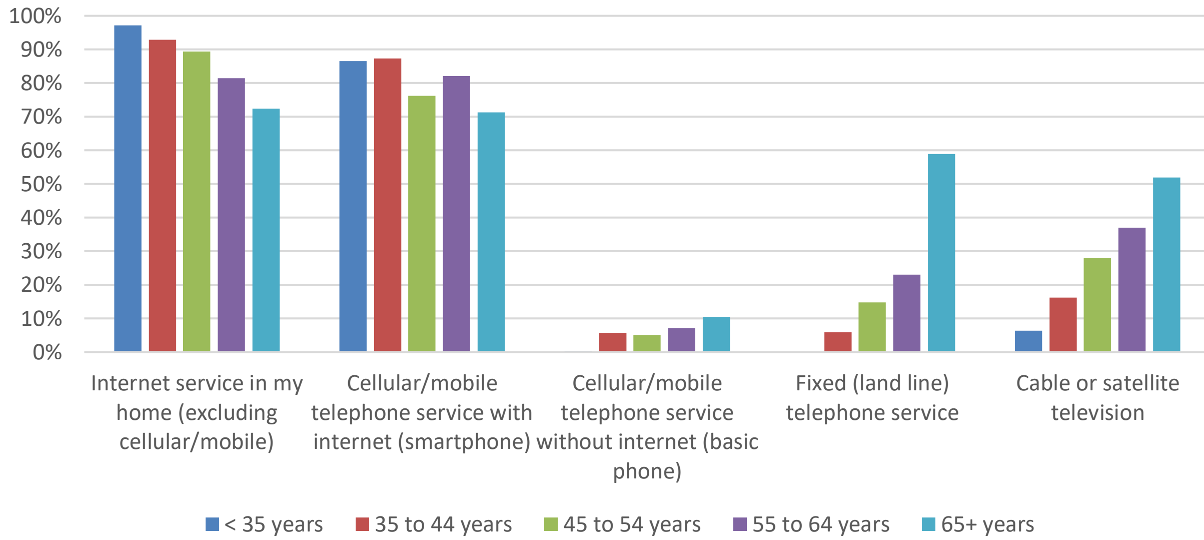
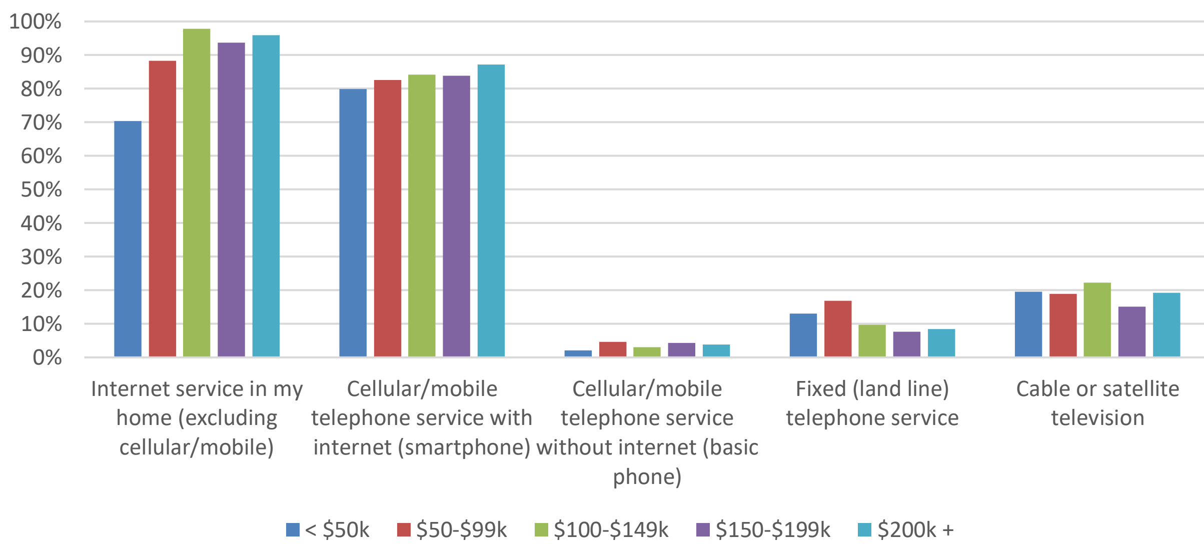


Figure 25: Services purchased by household income



Use of internet service is also correlated with household income. Lower-income households (less than $50,000 annual income) are less likely than households with a higher income to have internet access at home, as illustrated in Figure 25. Seventy percent of households earning under $50,000 per year have internet service in the home, and 80 percent have a smartphone. Keep in mind that respondents in lower-income households are disproportionately older; one-fourth are ages 65+.

Table 32: Internet Access by key demographics

	None/ No Response	Home Internet Connection	Smartphone	Both Home/ Smartphone	Total Internet Access	*Total Weighted Count*
TOTAL	**3%**	**14%**	**6%**	**77%**	**97%**	***604***
Respondent Age						
< 35 years	0%	13%	3%	84%	100%	*315*
35 to 44 years	1%	11%	6%	81%	99%	*90*
45 to 54 years	1%	23%	10%	66%	99%	*55*
55 to 64 years	7%	11%	11%	71%	93%	*49*
65 years and older	14%	15%	14%	57%	86%	*88*
Education						
HS education or less	12%	11%	31%	46%	88%	*51*
Two-year college/tech	8%	7%	40%	44%	92%	*25*
Four-year college degree	2%	17%	2%	79%	98%	*213*
Graduate, prof, doc degree	2%	13%	2%	83%	98%	*305*
Household Income						
Less than $50,000	10%	11%	20%	60%	90%	*98*
$50,000 to $99,999	3%	14%	8%	74%	97%	*93*
$100,000 to $149,999	2%	14%	1%	84%	98%	*92*
$150,000 to $199,999	1%	15%	5%	79%	99%	*83*
$200,000 or more	2%	11%	2%	85%	98%	*161*
Race/Ethnicity						
Hispanic/Latino	0%	9%	5%	86%	100%	*52*
Asian/South Asian, alone	0%	14%	3%	83%	100%	*110*
Black/African American, alone	8%	4%	29%	59%	92%	*58*
White, alone	4%	16%	3%	77%	96%	*322*
Other race/more than one	0%	11%	13%	76%	100%	*37*
Gender						
Female	4%	17%	8%	72%	96%	*275*
Male	2%	12%	6%	81%	98%	*282*
Total Household Size (Adults + Children)						
One household member	7%	12%	9%	72%	93%	*144*
Two household members	2%	16%	3%	79%	98%	*274*
Three household members	1%	16%	12%	71%	99%	*103*
Four+ household members	2%	6%	6%	85%	98%	*72*
Children in Household						
No Children in HH	3%	14%	6%	77%	97%	*509*
Children in HH	2%	10%	8%	79%	98%	*85*
Own or Rent Residence						
Own	6%	14%	5%	75%	94%	*178*
Rent/live with family/other	2%	14%	6%	78%	98%	*416*
Years at Residence						
Less than 1 year	0%	14%	0%	86%	100%	*108*
1 to 2 years	1%	12%	3%	84%	99%	*161*
3 to 4 years	0%	20%	6%	74%	100%	*81*
5 or more years	6%	14%	11%	69%	94%	*245*

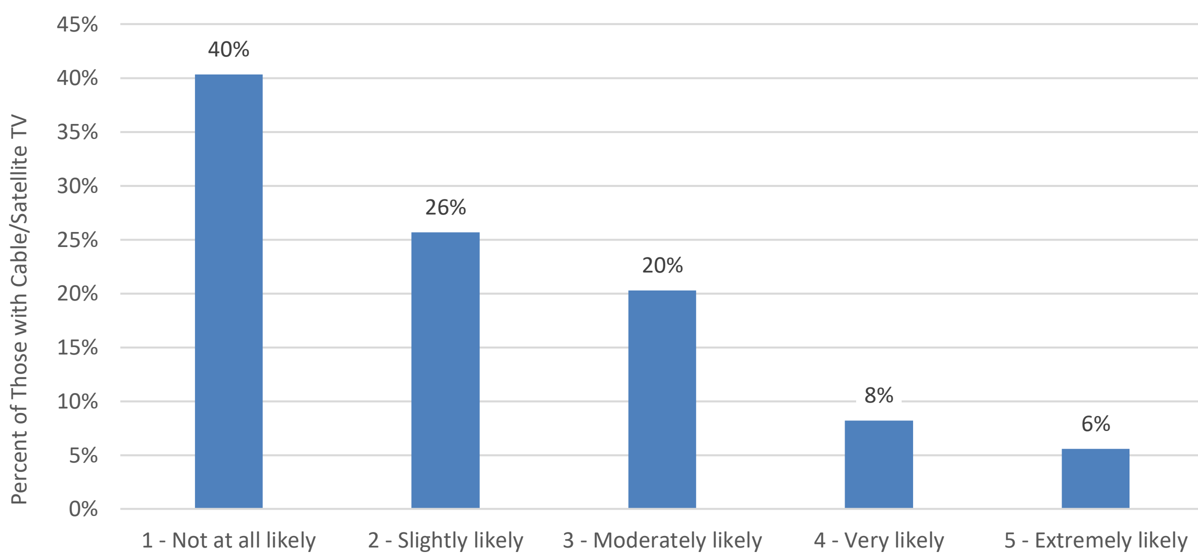
Overall, 97 percent of respondents indicated having some internet access, as illustrated in Table 32. The remaining 3 percent of respondents do not have internet or did not respond. About 77 percent of respondents have both home internet service and a cellular/mobile telephone service with internet (smartphone). Another 6 percent of respondents have a smartphone only (no home internet), and 14 percent have a home connection only (no smartphone).

As discussed earlier, older respondents and those in lower-income households are less likely than their counterparts to have internet access. Additionally, those below a four-year college level education were less likely to report having internet access.

Cancel cable or satellite TV for streaming

Cable and satellite television subscribers were asked how likely they would be to cancel their service in the next 12 months and watch TV shows and movies online. As shown in Figure 26, four in 10 subscribers said they are not at all likely to cancel their subscription, and another 26 percent are only slightly likely. Another 20 percent of subscribers are moderately likely to cancel their cable or satellite TV subscription, while 8 percent are very likely and 6 percent are extremely likely.

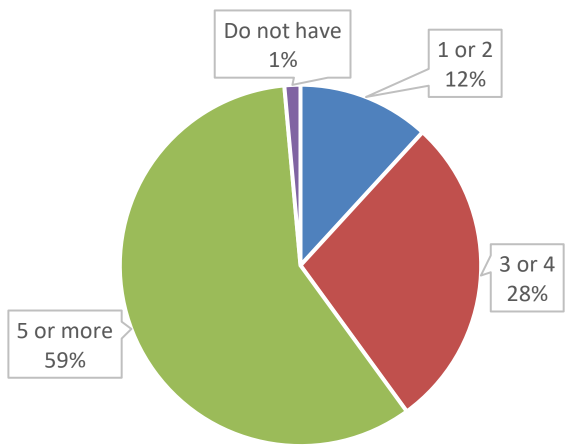
Figure 26: Likelihood of canceling cable or satellite television in next 12 months



Number of personal computing devices in the home

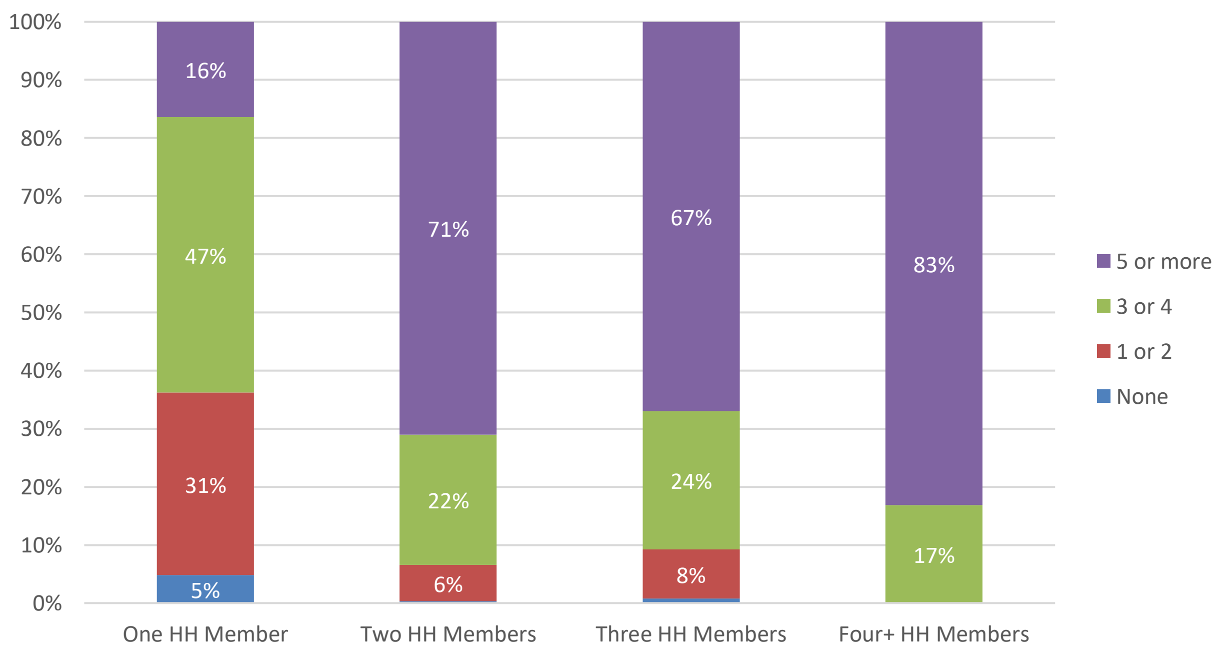
Respondents were asked to indicate the number of personal computing devices they have in the home. As shown in Figure 27, 59 percent of households have five or more devices, and another 28 percent have three or four devices in the home.

Figure 27: Number of personal computing devices in home



The number of personal computing devices in the home is strongly associated with household size. Sixteen percent of one-member households have five or more devices, compared with 83 percent of those with four or more household members (see Figure 28).

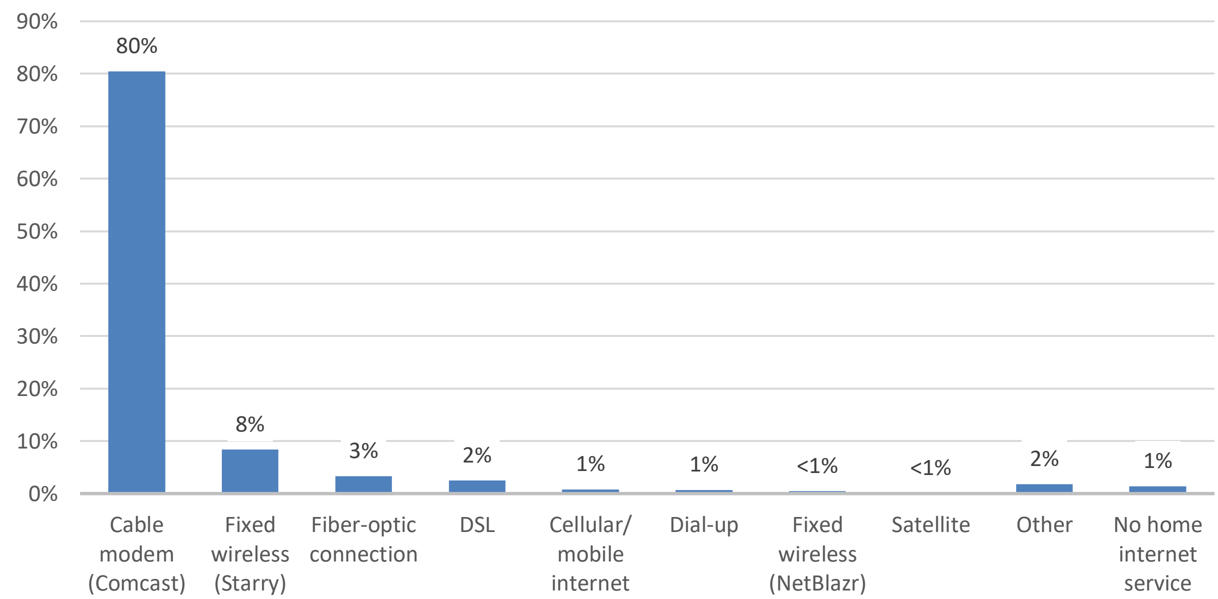
Figure 28: Number of personal computing devices in home by household size



Primary home internet service

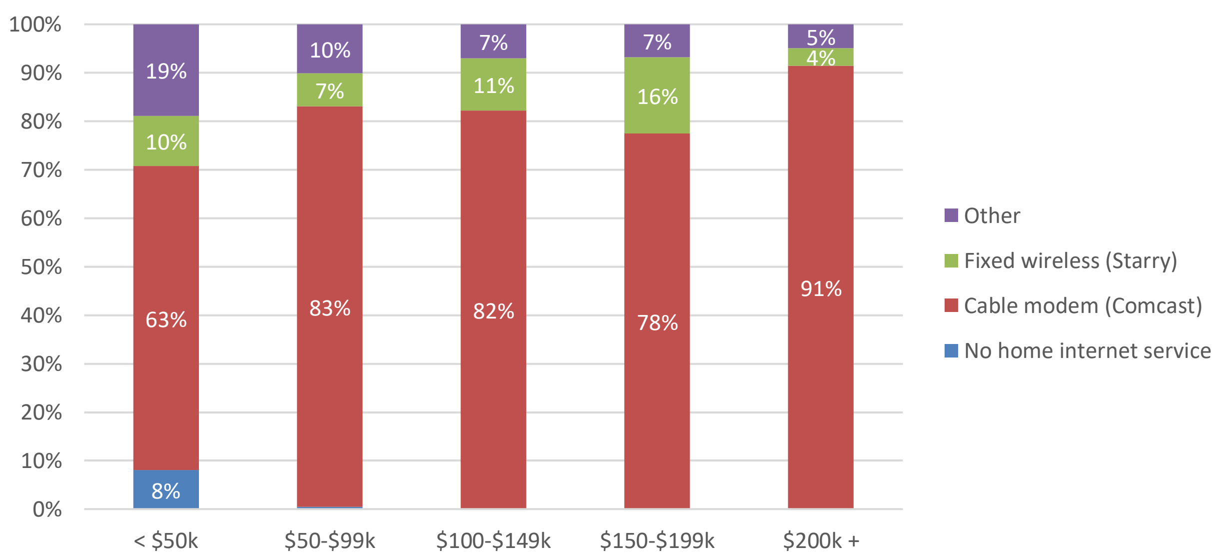
Almost all respondents reported having home internet service. Cable modem (80 percent) is the leading internet service used, followed by fixed wireless service from Starry (8 percent), as shown in Figure 29. Very few respondents have another service.

Figure 29: Primary home internet service



Comcast is the leading ISP used across all income groups. Respondents earning under $50,000 per year are less likely to have internet service (see Figure 30).

Figure 30: Primary internet service by household income



Internet service aspects

Home internet subscribers were asked to evaluate their satisfaction with various internet service aspects. This was compared with importance ratings given for these same aspects. The importance and satisfaction levels among internet users are compared in the following tables and graphs.

Importance

Respondents rated connection reliability as the most important home internet service aspect, with nearly nine in 10 saying it is extremely important, as shown in Table 33. Sixty-four percent of subscribers said connection speed is extremely important. Fewer respondents said price of service (47 percent) and overall customer service (27 percent) is extremely important. The ability to bundle with TV and phone service is less important compared with other service aspects.

Table 33: Importance of internet service aspects

Service Aspect	Mean	Percentages
Speed of Connection	4.5	6%, 28%, 64%
Reliability of Connection	4.9	11%, 88%
Price of Services	4.3	15%, 35%, 47%
Overall Customer Service	3.8	8%, 31%, 33%, 27%
Ability to Bundle with TV and Phone	1.7	66%, 12%, 10%, 5%, 7%

1 - Not at all important; 2 - Slightly important; 3 - Moderately important; 4 - Very important; 5 - Extremely important

Satisfaction

Overall, respondents are moderately to very satisfied with their internet service, as shown in Table 34. About two-thirds of respondents are very or extremely satisfied with connection speed, and nearly six in 10 are very or extremely satisfied with reliability. Subscribers are less satisfied with cost compared with other service aspects, which is typical in satisfaction surveys.

Table 34: Satisfaction with internet service aspects

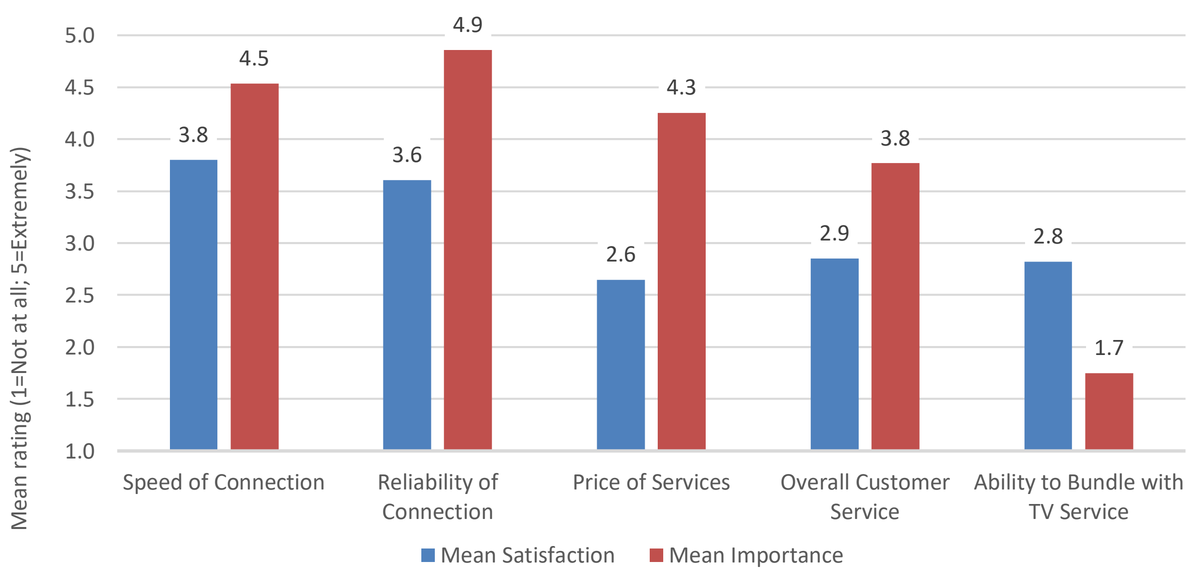
Service Aspect	Mean	Percentages
Speed of Connection	3.8	3% 8% 22% 38% 29%
Reliability of Connection	3.6	5% 10% 27% 35% 23%
Price of Services	2.6	21% 27% 29% 13% 10%
Overall Customer Service	2.9	16% 19% 38% 15% 11%
Ability to Bundle with TV and Phone	2.8	18% 13% 47% 11% 10%

■ 1 - Very dissatisfied ■ 2 - Slightly satisfied ■ 3 - Moderately satisfied
■ 4 - Very satisfied ■ 5 - Extremely satisfied

Performance

Comparing respondents' stated importance and satisfaction with service aspects allows an evaluation of how well internet service providers are meeting the needs of customers (see Figure 31). Aspects that have higher stated importance than satisfaction can be considered areas in need of improvement. Aspects that have higher satisfaction than importance are areas where the market is meeting or exceeding customers' needs. However, it should be cautioned that the extremely high level of importance placed on some aspects (such as reliability) may make it nearly impossible to attain satisfaction levels equal to importance levels.

Figure 31: Importance of and satisfaction with internet service aspects



The difference between importance and satisfaction of home internet aspects is also presented in the "gap" analysis table (see Table 35). The largest gap between importance and performance is for price of services, followed by reliability of connection. The ability to bundle is exceeding expectations, given the low importance placed on this service aspect.

Table 35: Internet service aspect "gap" analysis

	Mean Satisfaction	Mean Importance	GAP < = >	Customer Expectations
Price of Services	2.6	4.3	-1.6	Not Met
Reliability of Connection	3.6	4.9	-1.3	Not Met
Overall Customer Service	2.9	3.8	-0.9	Not Met
Speed of Connection	3.8	4.5	-0.7	Not Met
Ability to Bundle with TV Service	2.8	1.7	1.1	Met

Few differences in importance across connection types were found; however, those with "other" providers placed somewhat more importance on ability to bundle service compared with cable modem (Comcast) and fixed wireless (Starry) customers (see Figure 32). Starry subscribers have a higher level of satisfaction with connection speed, price, and overall customer service, as shown in Figure 33.

Figure 32: Importance of internet service aspects by primary internet service

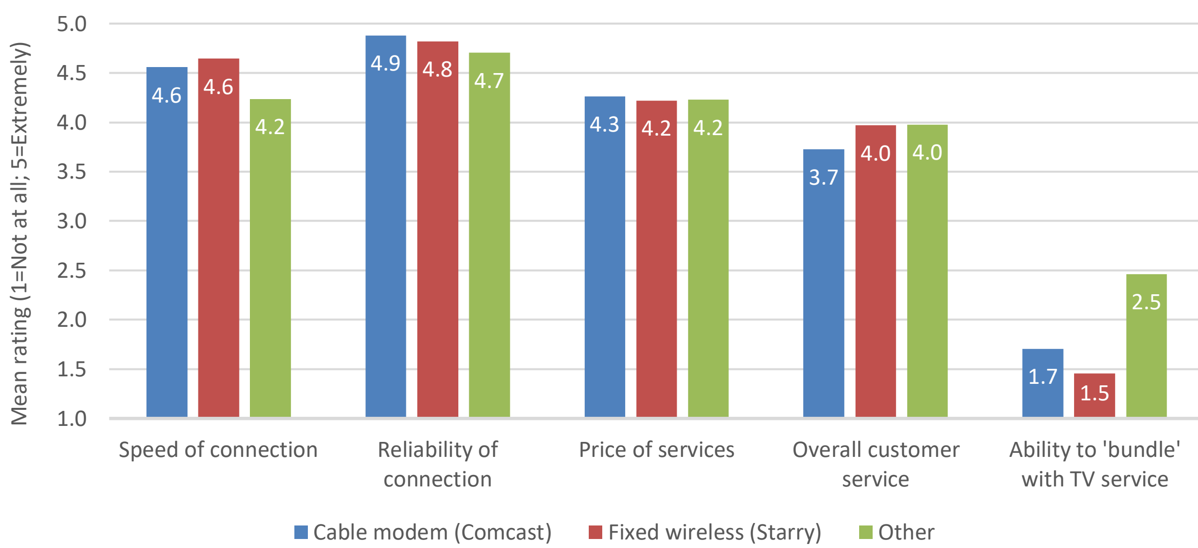
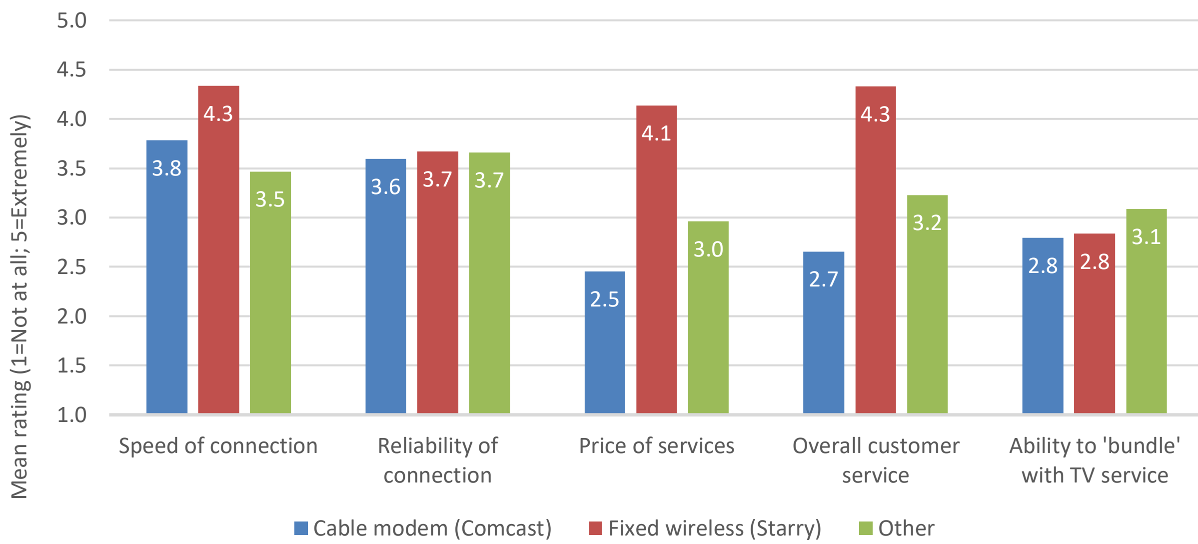


Figure 33: Satisfaction with internet service aspects by primary internet service



As illustrated in Table 36, Starry is better meeting customer expectations compared with Comcast for connection speed, price, customer service, and ability to bundle. The leading provider types are performing equally well for connection reliability.

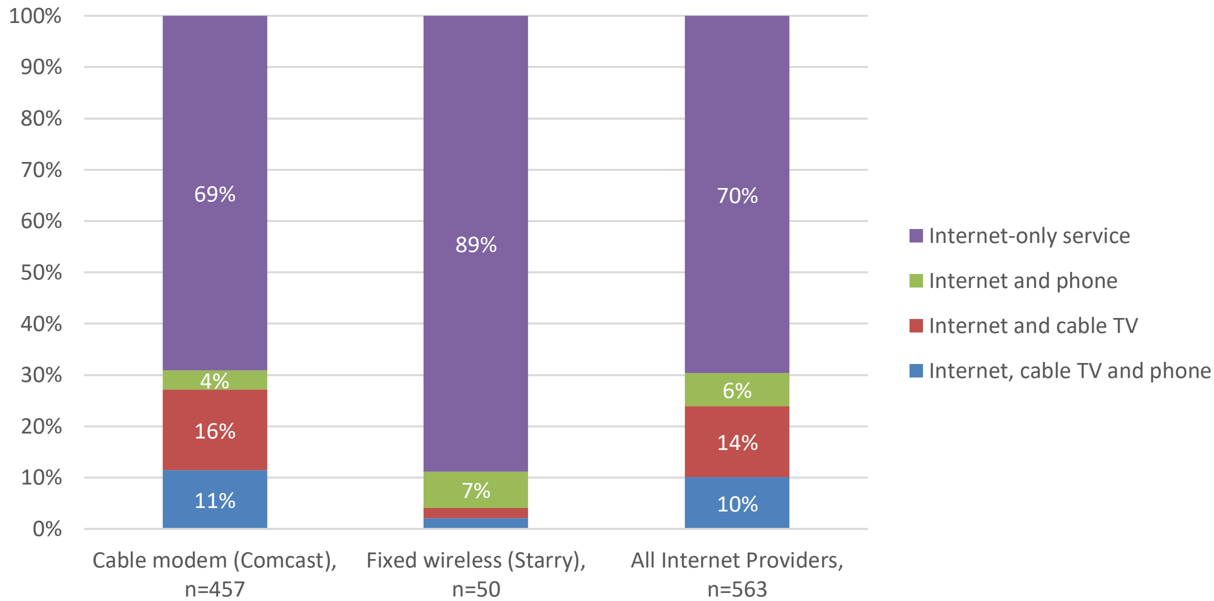
Table 36: Gap index score by primary internet service

	Satisfaction / Importance Gap Index*				
	Connection Speed	Connection Reliability	Price of Service	Customer Service	Ability to Bundle
Cable modem (Comcast)	83%	74%	58%	71%	164%
Fixed wireless (Starry)	93%	76%	98%	109%	195%
Other	82%	78%	70%	81%	125%
ISP Average	***84%***	***74%***	***62%***	***76%***	***161%***
***Percent of expectations met = Satisfaction / Importance**					

Internet service cost

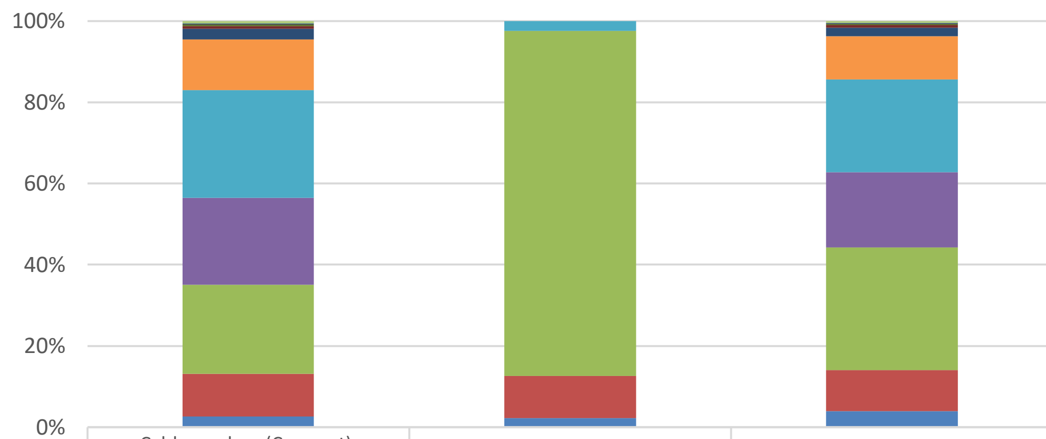
Respondents were asked to give the cost of their primary internet service and whether they bundle their service. As illustrated in Figure 34, most home internet subscribers purchase internet-only service. About three-in 10 cable modem (Comcast) customers bundle their internet with another service.

Figure 34: Bundle home internet service by primary internet service



The estimated monthly average cost for internet service-only is $70 overall, with most customers paying under $100 per month for service (see Figure 35). Almost all Starry subscribers pay $60 or less per month for internet-only service. Cable modem (Comcast) subscribers pay an estimated monthly average of $74 for internet-only service.

Figure 35: Monthly price for internet-only service by primary internet service

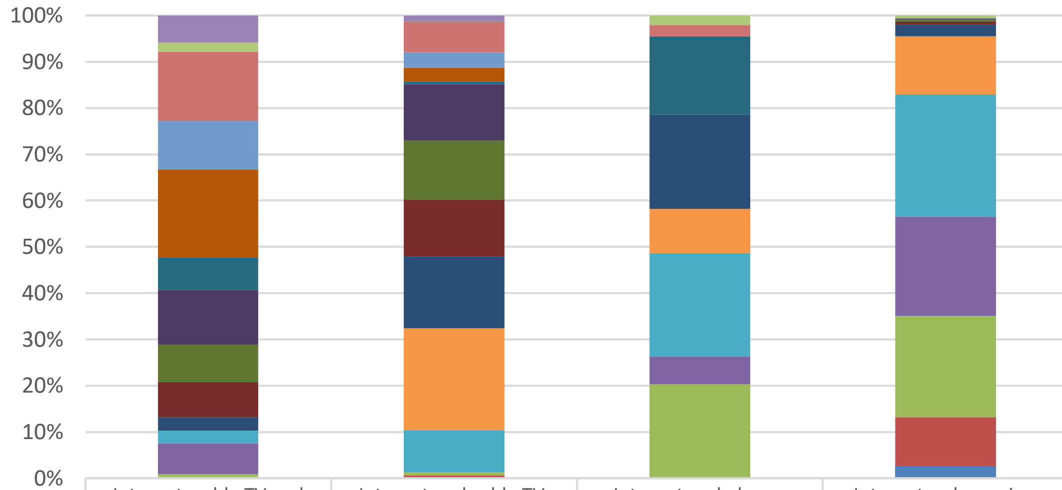


	Cable modem (Comcast), n=313	Fixed wireless (Starry), n=45	All Internet Providers, n=389
More than $300	0%	0%	0%
$281 to $300	1%	0%	0%
$261 to $280	0%	0%	0%
$241 to $260	0%	0%	0%
$221 to $240	0%	0%	0%
$201 to $220	0%	0%	0%
$181 to $200	0%	0%	0%
$161 to $180	0%	0%	0%
$141 to $160	1%	0%	1%
$121 to $140	3%	0%	2%
$101 to $120	12%	0%	11%
$81 to $100	26%	2%	23%
$61 to $80	21%	0%	19%
$41 to $60	22%	85%	30%
$21 to $40	11%	10%	10%
$0 to $20	3%	2%	4%

<u>Estimated Monthly Avg:</u>
Total: $70
Cable modem (Comcast): $74
Fixed wireless (Starry): $48

The estimated monthly average costs for bundled services for cable modem subscribers is illustrated in Figure 36. Subscribers pay an estimated monthly average of $208 for internet, cable TV, and phone services bundled.

Figure 36: Monthly price by bundle for cable modem (Comcast) subscribers



	Internet, cable TV and phone, n=49	Internet and cable TV, n=70	Internet and phone, n=17	Internet-only service, n=313
More than $300	6%	1%	0%	0%
$281 to $300	2%	0%	2%	1%
$261 to $280	15%	7%	2%	0%
$241 to $260	11%	3%	0%	0%
$221 to $240	19%	3%	0%	0%
$201 to $220	7%	1%	17%	0%
$181 to $200	12%	12%	0%	0%
$161 to $180	8%	13%	0%	0%
$141 to $160	8%	12%	0%	1%
$121 to $140	3%	16%	20%	3%
$101 to $120	0%	22%	10%	12%
$81 to $100	3%	9%	22%	26%
$61 to $80	7%	0%	6%	21%
$41 to $60	1%	1%	20%	22%
$21 to $40	0%	1%	0%	11%
$0 to $20	0%	0%	0%	3%

Estimated Monthly Avg:
Internet, cable, phone: $208
Internet and cable: $144
Internet and phone: $119
Internet-only: $74

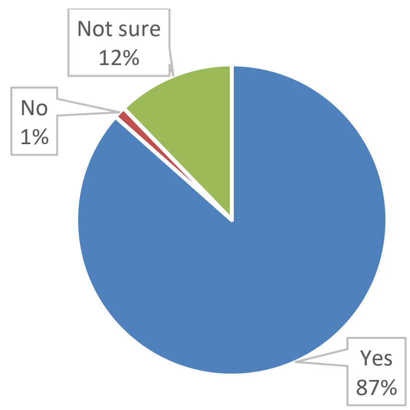
Opinions about internet service

Respondents were asked to assess the need for an additional internet service provider in Cambridge, interest in acquiring services from the new provider, and willingness to purchase from a new provider at various price points. Additionally, respondents were asked their opinions about the City's role in providing or promoting broadband communications services within the area.

Need for additional ISP in Cambridge

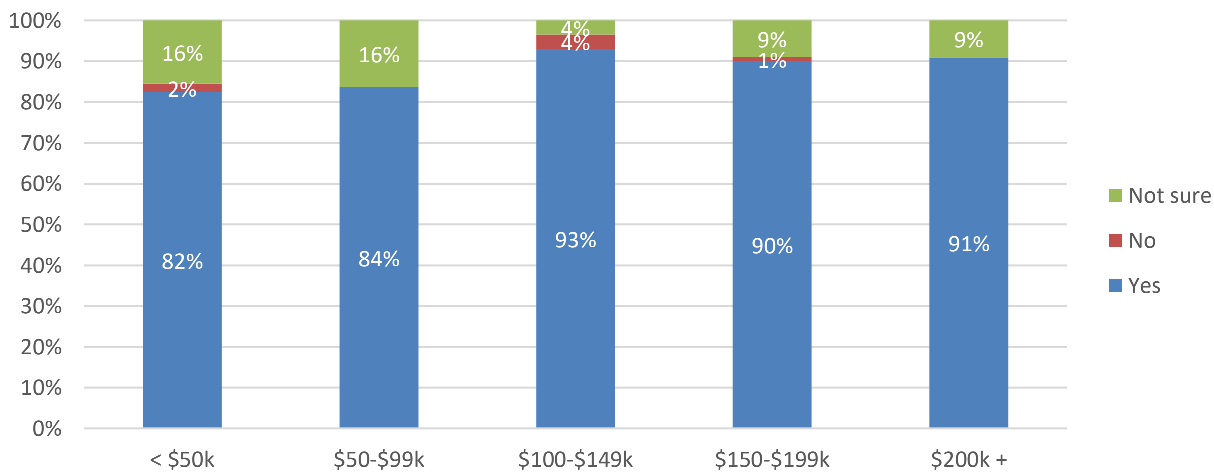
As shown in Figure 37, 87 percent of respondents agreed the City of Cambridge needs an additional internet service provider, while 12 percent were unsure, and 1 percent said it does not.

Figure 37: Would like to see additional ISP in Cambridge



Respondents with a household income under $100,000 were less likely than those with a higher household income to agree they would like to see an additional ISP in Cambridge, and they were more likely to be unsure (see Figure 38).

Figure 38: Would like to see additional ISP in Cambridge by household income



Likelihood of acquiring services from new ISP in Cambridge

More than one-half of respondents said they would be very likely (29 percent) or extremely likely (25 percent) to acquire services from a new internet service provider in Cambridge (see Figure 39). Another 35 percent would be moderately likely, 8 percent would be slightly likely, and 4 percent would be not at all likely to acquire internet service from a new provider.

Cable modem (Comcast) subscribers would be more likely than fixed wireless (Starry) subscribers to purchase services from a new provider. Specifically, 58 percent of cable modem subscribers would be very or extremely likely to acquire new internet service, compared with 17 percent of Starry subscribers.

Figure 39: Likelihood of acquiring new internet service by current internet provider

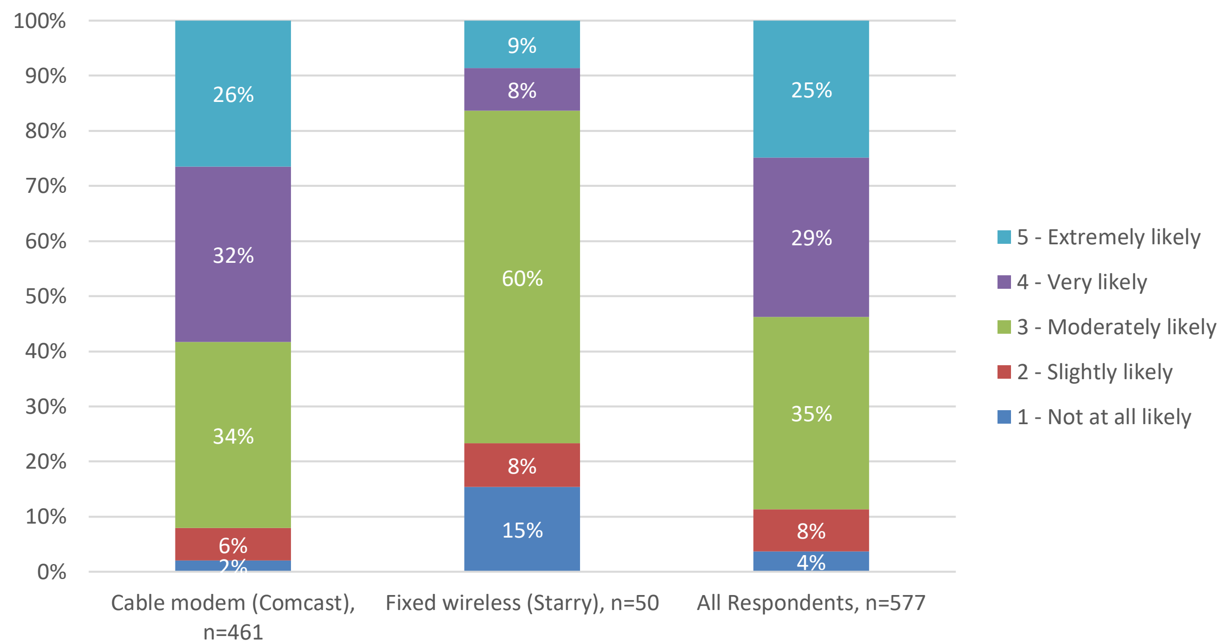


Table 37 highlights the likelihood of acquiring services from a new internet provider by various demographic variables of interest. Likelihood of acquiring a new internet service does not vary significantly by most demographics, but newer residents (living in their households for two or fewer years) would be more likely than those living longer to acquire services.

Table 37: Likelihood of acquiring new internet service by key demographics

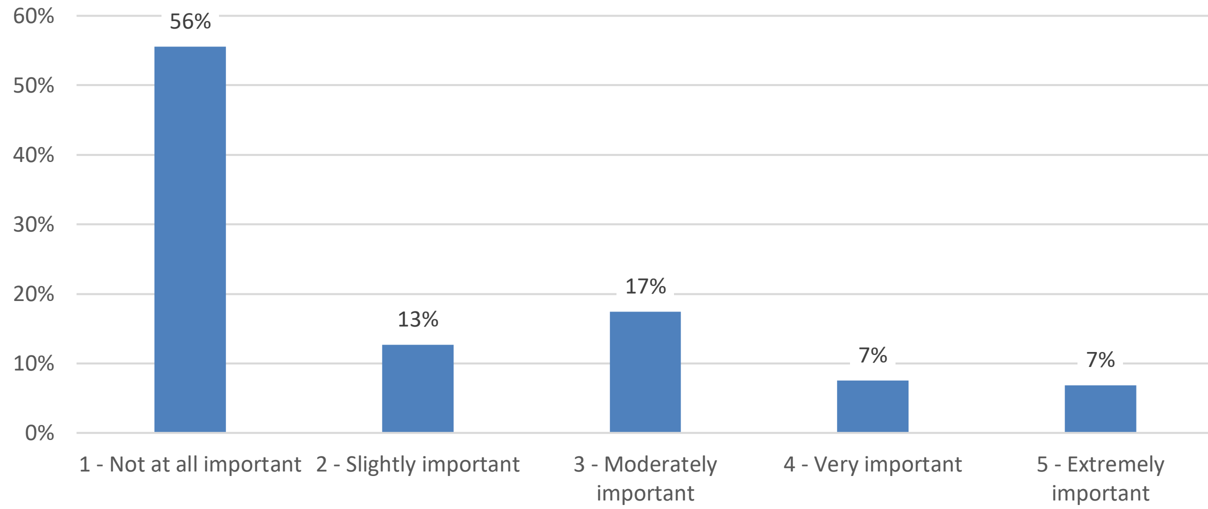
	1 – Not at all likely	2 – Slightly likely	3 – Moderately likely	4 – Very likely	5 – Extremely likely	*Total Weighted Count*
TOTAL	**4%**	**8%**	**35%**	**29%**	**25%**	***577***
Respondent Age						
< 35 years	4%	9%	40%	25%	22%	*304*
35 to 44 years	5%	8%	27%	20%	40%	*86*
45 to 54 years	0%	6%	34%	31%	29%	*53*
55 to 64 years	4%	5%	19%	53%	19%	*47*
65 years and older	5%	6%	35%	36%	18%	*79*
Education						
HS education or less	3%	8%	36%	28%	25%	*50*
Two-year college/tech	4%	5%	33%	28%	29%	*24*
Four-year college degree	4%	7%	33%	28%	28%	*200*
Graduate, prof, doc degree	4%	8%	36%	29%	22%	*294*

	1 – Not at all likely	2 – Slightly likely	3 – Moderately likely	4 – Very likely	5 – Extremely likely	*Total Weighted Count*
Household Income						
Less than $50,000	3%	5%	43%	36%	12%	*96*
$50,000 to $99,999	4%	11%	34%	23%	27%	*88*
$100,000 to $149,999	2%	5%	35%	34%	24%	*90*
$150,000 to $199,999	9%	5%	24%	36%	25%	*82*
$200,000 or more	2%	7%	37%	26%	29%	*154*
Race/Ethnicity						
Hispanic/Latino	0%	17%	36%	22%	25%	*52*
Asian/South Asian, alone	6%	11%	41%	23%	20%	*101*
Black/African American, alone	0%	2%	38%	38%	22%	*57*
White, alone	4%	7%	34%	31%	25%	*308*
Other race/more than one	5%	4%	28%	28%	35%	*36*
Gender						
Female	4%	11%	37%	30%	19%	*261*
Male	4%	5%	34%	30%	27%	*272*
Total Household Size (Adults + Children)						
One household member	4%	14%	32%	27%	23%	*139*
Two household members	3%	6%	38%	29%	24%	*257*
Three household members	6%	1%	38%	25%	30%	*101*
Four+ household members	3%	13%	25%	37%	22%	*70*
Children in Household						
No Children in HH	4%	7%	36%	29%	24%	*485*
Children in HH	5%	10%	26%	29%	29%	*83*
Own or Rent Residence						
Own	4%	6%	27%	34%	29%	*166*
Rent/live with family/other	4%	8%	38%	26%	23%	*402*
Years at Residence						
Less than 1 year	6%	7%	47%	18%	21%	*101*
1 to 2 years	3%	11%	37%	31%	18%	*161*
3 to 4 years	6%	4%	23%	27%	40%	*76*
5 or more years	2%	7%	32%	33%	26%	*231*

Importance of new ISP offering video and phone services

Most respondents said the importance of a new internet provider also offering video and phone services is not at all important (56 percent) or slightly important (13 percent), as illustrated in Figure 40. Another 17 percent said offering video and phone services is moderately important, while a smaller segment of respondents said it is very important (7 percent) or extremely important (7 percent).

Figure 40: Importance of offering video and phone services



As shown in Figure 41 to Figure 43, the importance of a new ISP offering video and phone service is greater for older respondents, those earning under $50,000 per year, and those with a lower education level.

Figure 41: Importance of offering video and phone services by respondent age

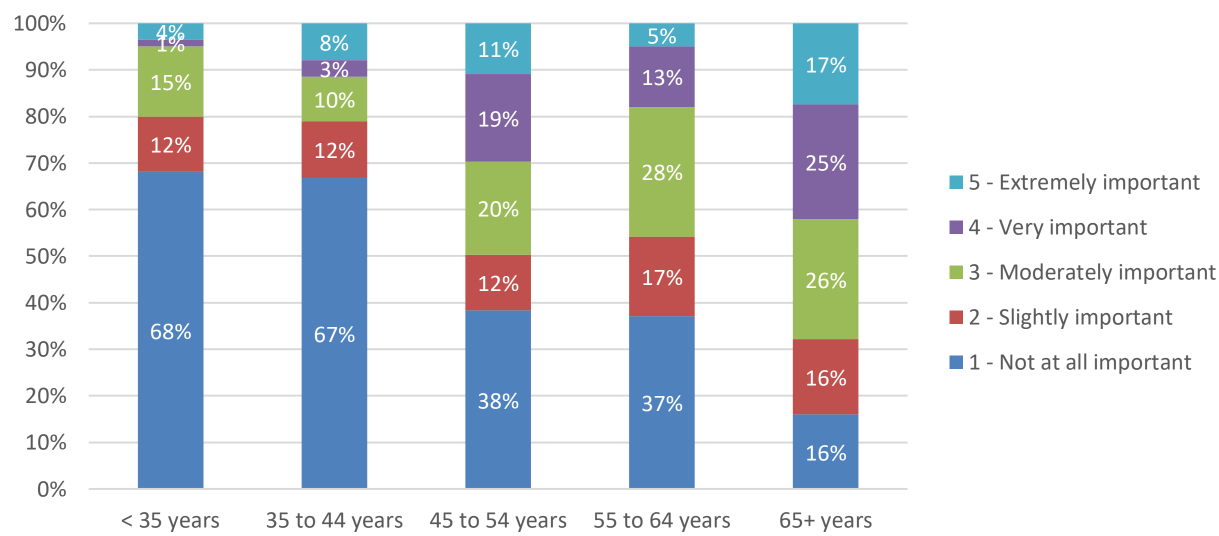


Figure 42: Importance of offering video and phone services by household income

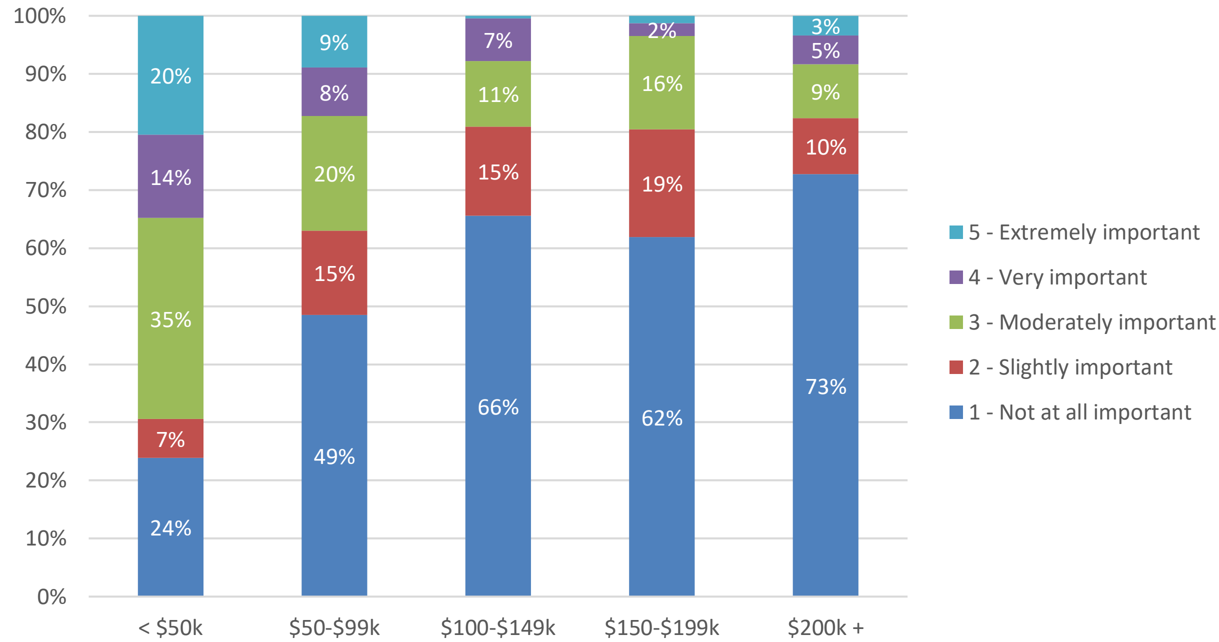
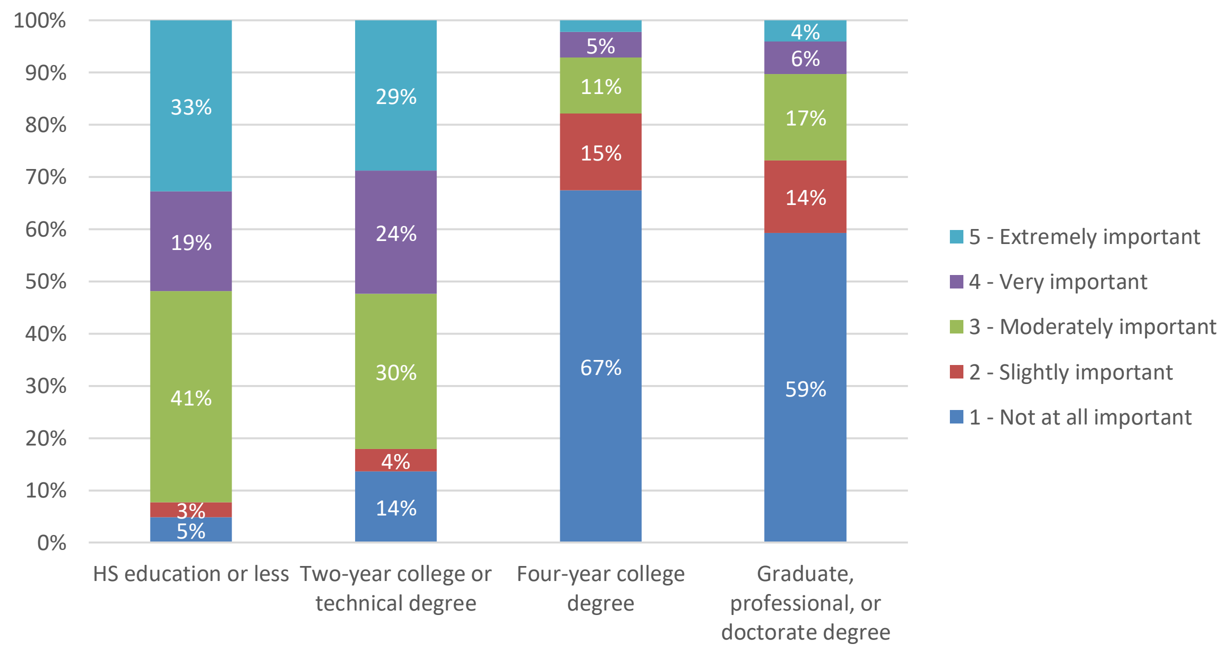


Figure 43: Importance of offering video and phone services by education level



Willingness to purchase 100 Mbps internet service

Respondents were asked if they would be willing to purchase 100 Mbps internet service for various price levels from a new Cambridge internet service provider. The mean willingness to purchase across this array of questions is illustrated Figure 44, while detailed responses are illustrated in Figure 45.

Respondents' willingness to purchase 100 Mbps internet service is high at $30 per month (4.5 mean), but it drops considerably as the price increases. The mean rating falls to 3.8 at a price point of $50 per month, 2.7 at a price point of $70 per month, 2.0 at a price point of $90 per month, and 1.6 at a price point of $110 per month (slightly willing). From another perspective, 76 percent of respondents are extremely willing to purchase 100 Mbps internet for $30 per month, dropping to 5 percent at $110 per month.

Figure 44: Willingness to purchase 100 Mbps internet at various price levels (mean ratings)

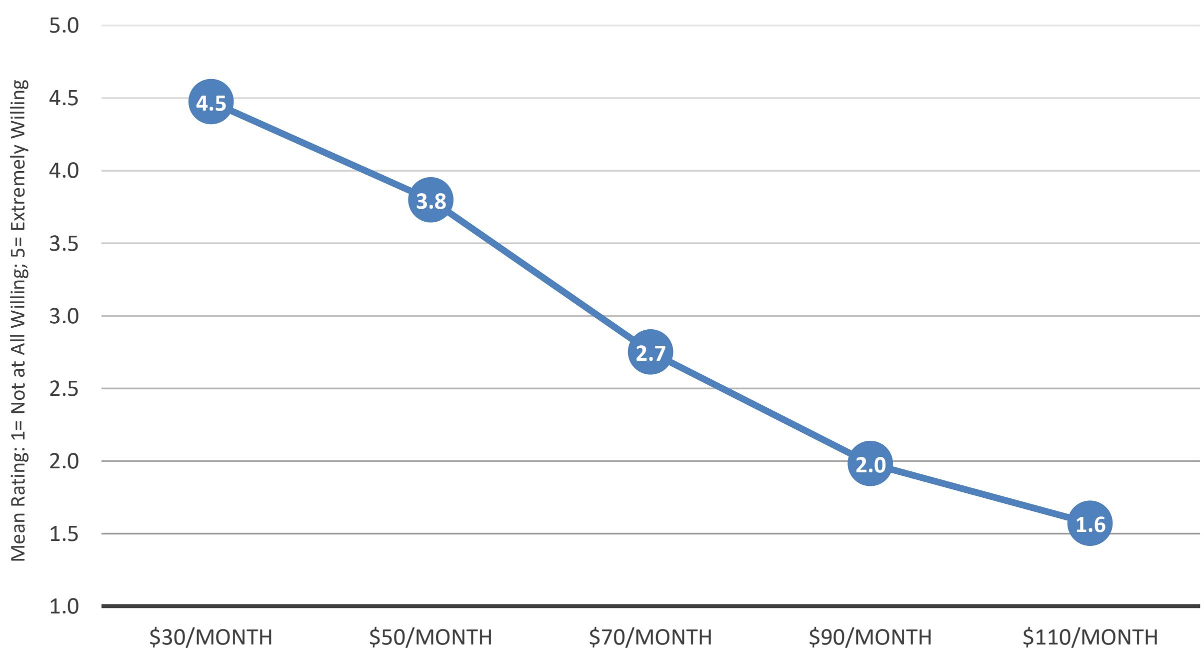
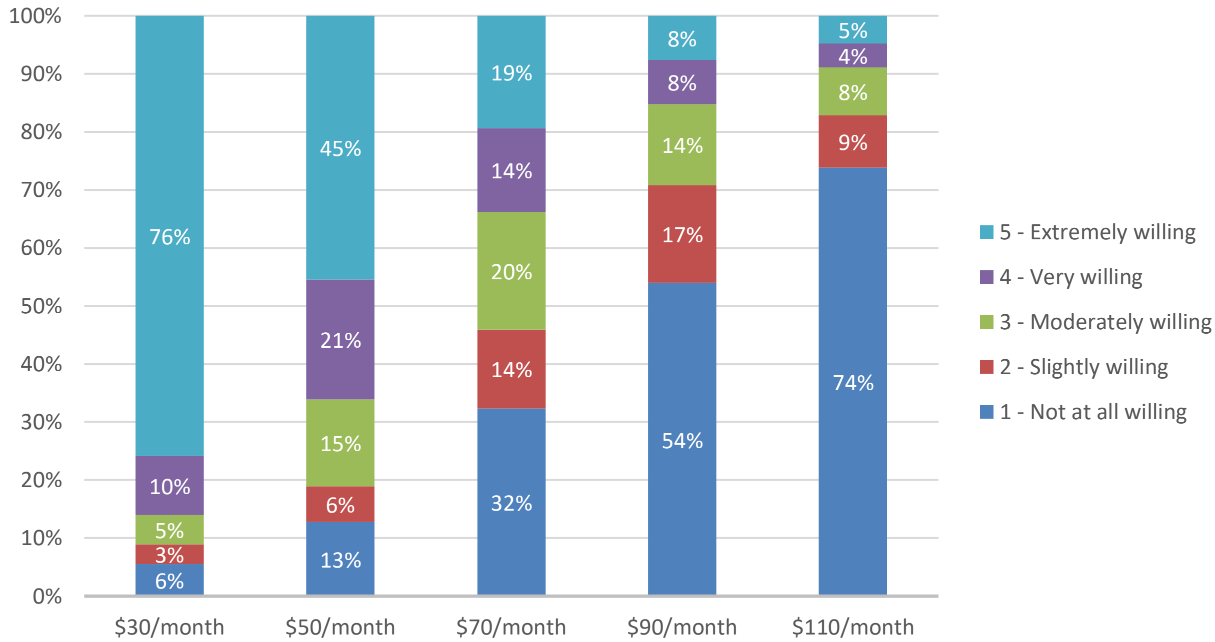
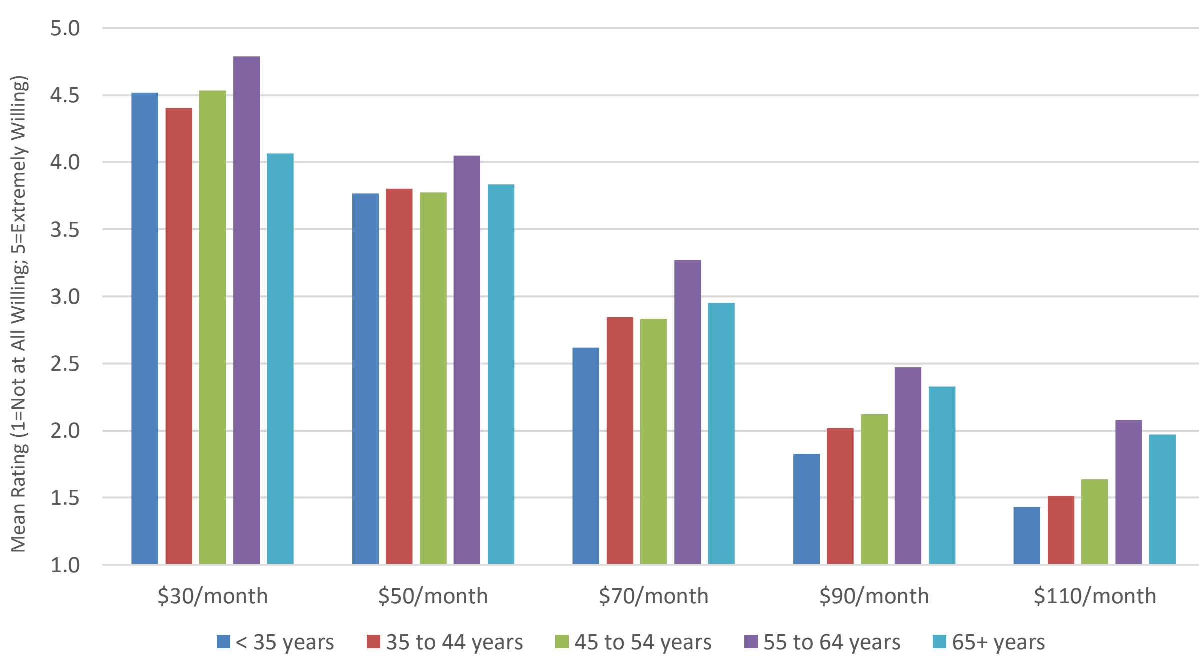


Figure 45: Willingness to purchase 100 Mbps internet at various price levels



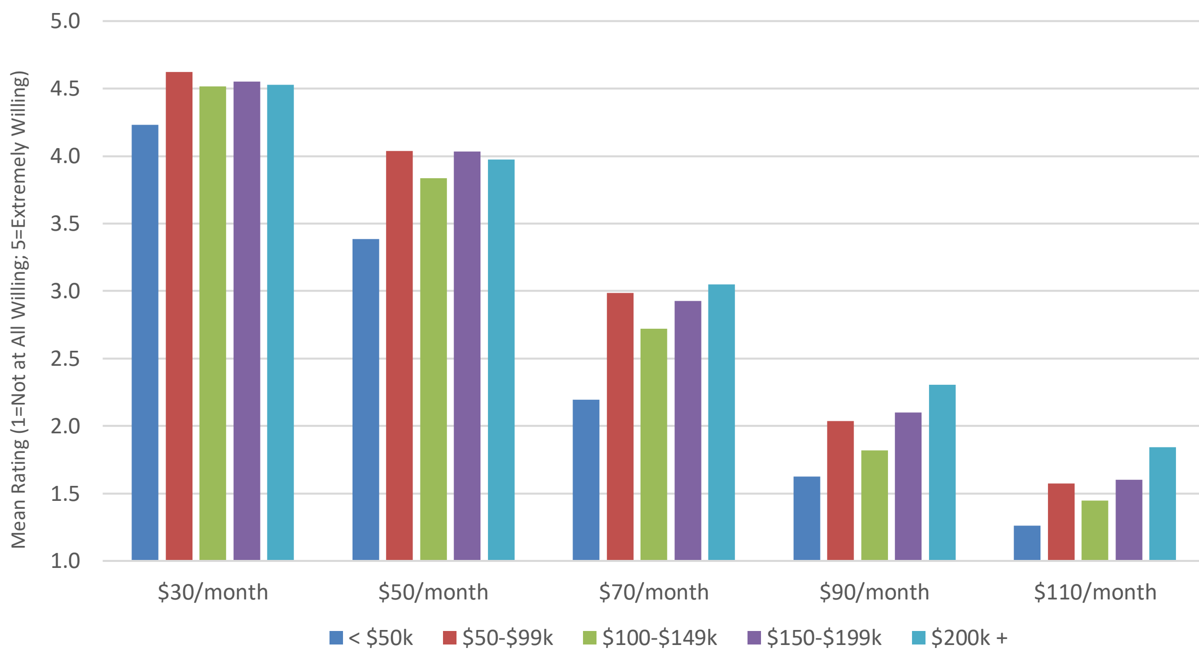
Older respondents would be more willing than younger respondents to purchase 100 Mbps service from a new provider, particularly at the higher price points (see Figure 46).

Figure 46: Willingness to purchase 100 Mbps internet service by respondent age



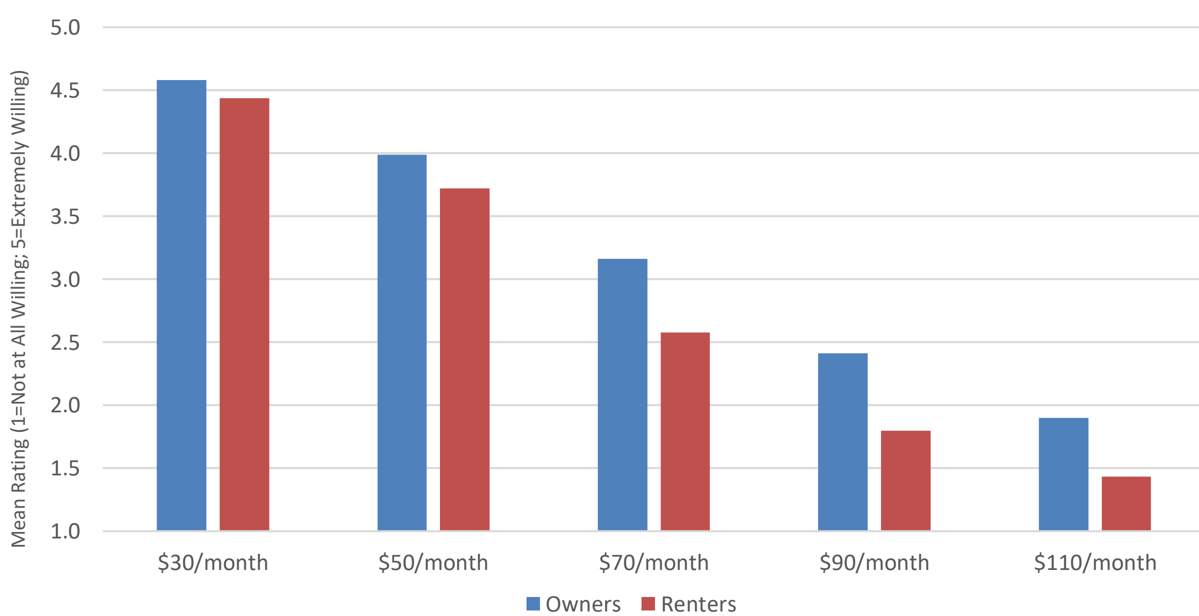
Respondents in lower-income households would be less willing than those with higher household income to purchase 100 Mbps internet service (see Figure 47).

Figure 47: Willingness to purchase 100 Mbps internet service by household income



Homeowners would be more likely than renters to purchase high-speed internet at various price points (see Figure 48).

Figure 48: Willingness to purchase 100 Mbps internet service by home ownership



Willingness to purchase 1 Gbps internet service

Respondents were asked if they would be willing to purchase 1 Gbps internet service for various price levels from a new Cambridge internet service provider. The mean willingness to purchase across this array of questions is illustrated in Figure 49, while detailed responses are illustrated in Figure 50.

Respondents' willingness to purchase 1 Gbps internet service is high at $30 per month (4.8 mean) and $50 per month (4.5 mean), but it drops considerably as the price increases, to 2.2 at a price point of $110 per month (slightly to moderately willing). From another perspective, 89 percent of respondents are extremely willing to purchase 1 Gbps internet for $30 per month, dropping to 13 percent at $110 per month.

Figure 49: Willingness to purchase 1 Gbps internet at various price levels (mean ratings)

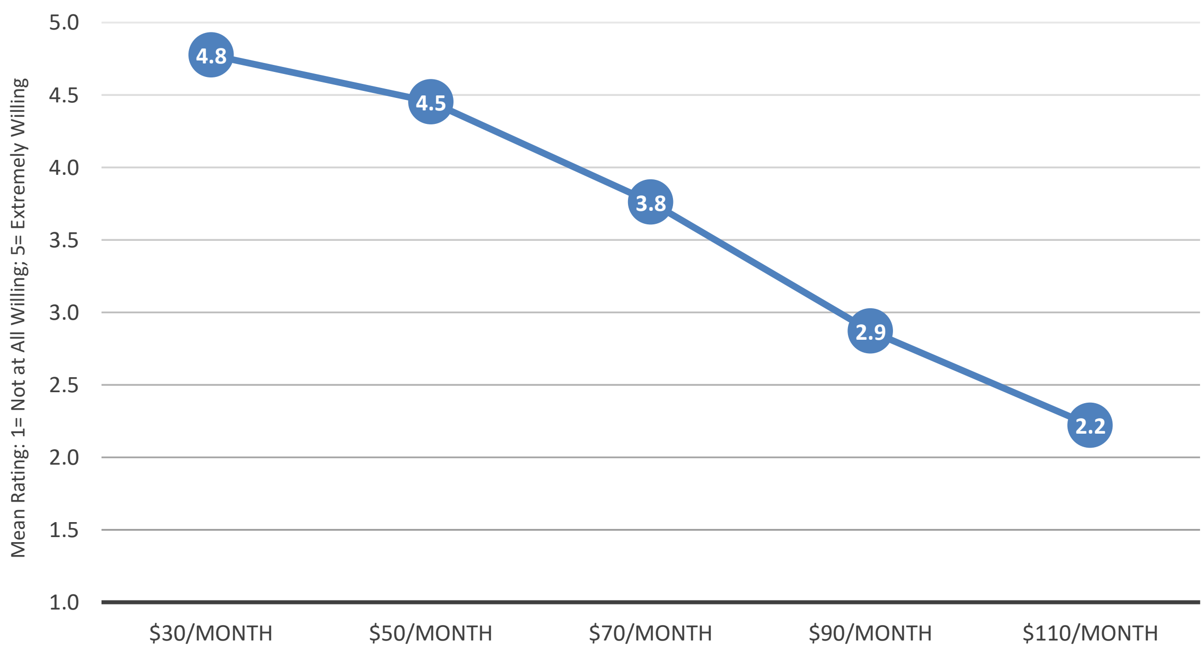
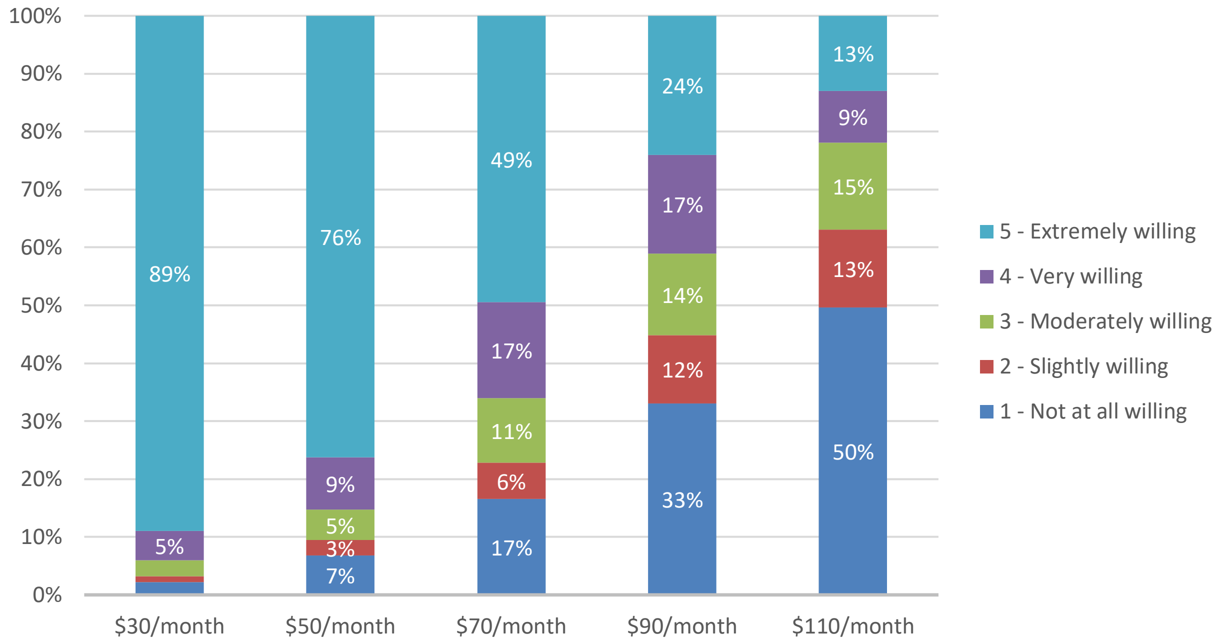


Figure 50: Willingness to purchase 1 Gbps internet at various price levels

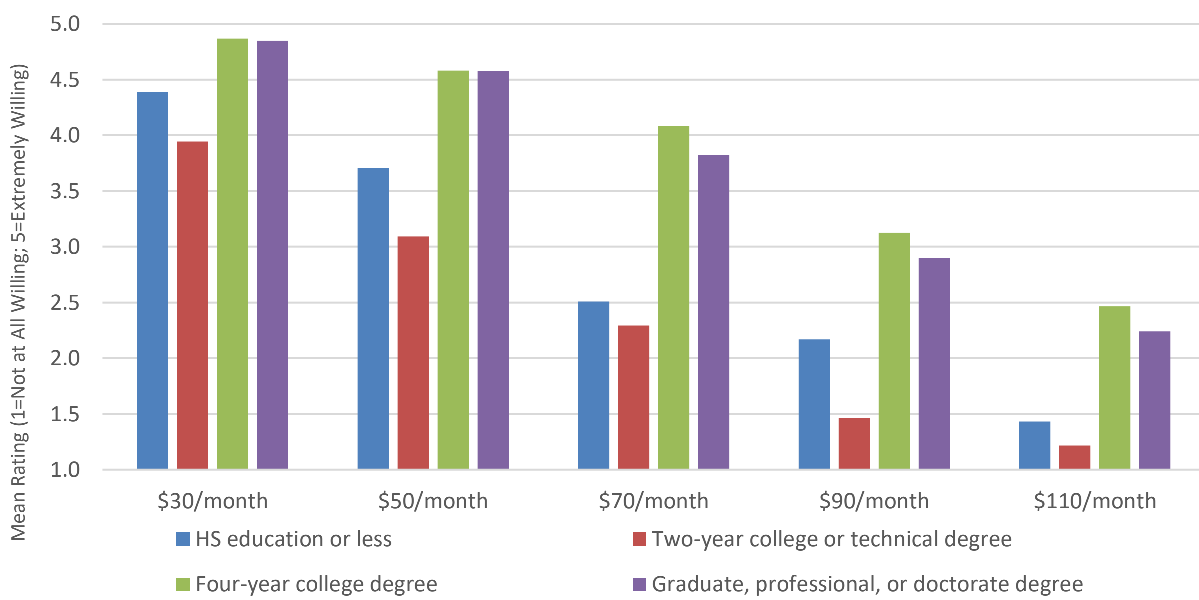


Respondents with a household income of less than $50,000 would be less likely than those with a higher household income to purchase 1 Gbps internet service at various price points (see Figure 51).

Figure 51: Willingness to purchase 1 Gbps internet service by household income

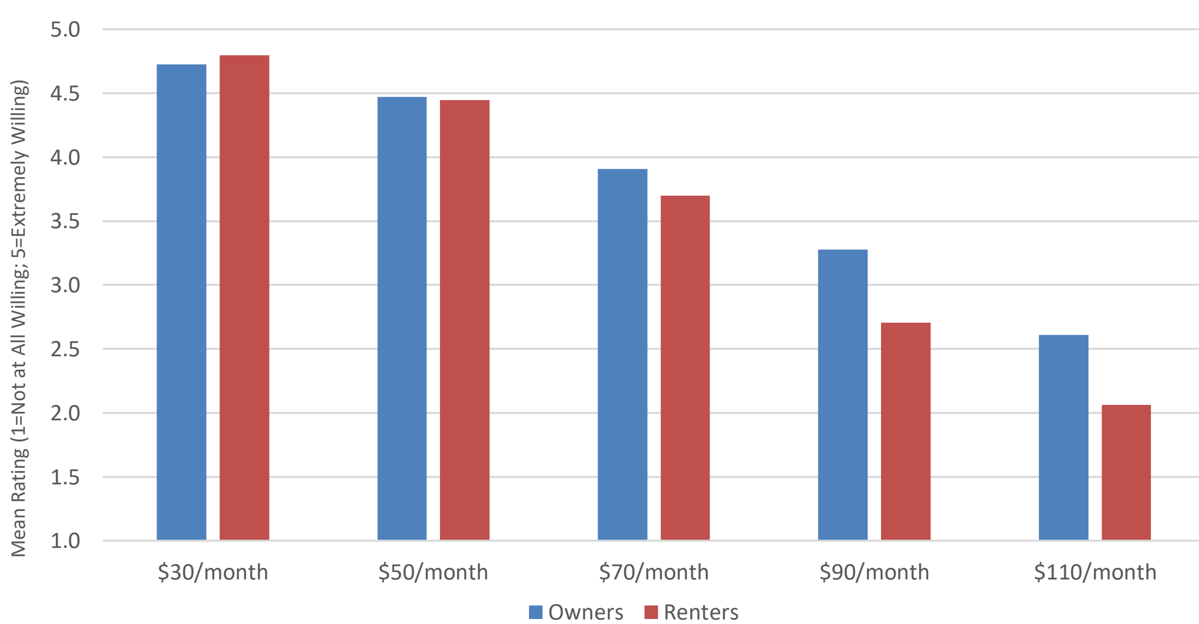
Respondents with a four-year college education or higher would be more willing than those with less education to purchase very high-speed internet service at various price points (see Figure 52).

Figure 52: Willingness to purchase 1 Gbps internet service by education level



Homeowners are more willing than renters to purchase 1 Gbps internet service at higher price points (see Figure 53).

Figure 53: Willingness to purchase 1 Gbps internet service by home ownership



Willingness to pay temporary per-household fee

Respondents were asked their willingness to pay a temporary per-household fee at various price levels for 10 years to help spread the initial construction cost of a new fiber optic broadband network over a longer period. The mean willingness to purchase across this array of questions is illustrated Figure 54, while detailed responses are illustrated in Figure 55.

Overall, respondents are slightly to moderately willing to pay a temporary fee to help cover construction costs at various price points. The mean rating falls from a high of 3.6 at $20 per month for 10 years to 1.6 at $60 per month for 10 years. From another perspective, 43 percent of respondents are extremely willing to pay a temporary per-household fee for $20 per month, dropping to 6 percent at $60 per month.

Figure 54: Willingness to pay temporary per-household fee for 10 years (mean ratings)

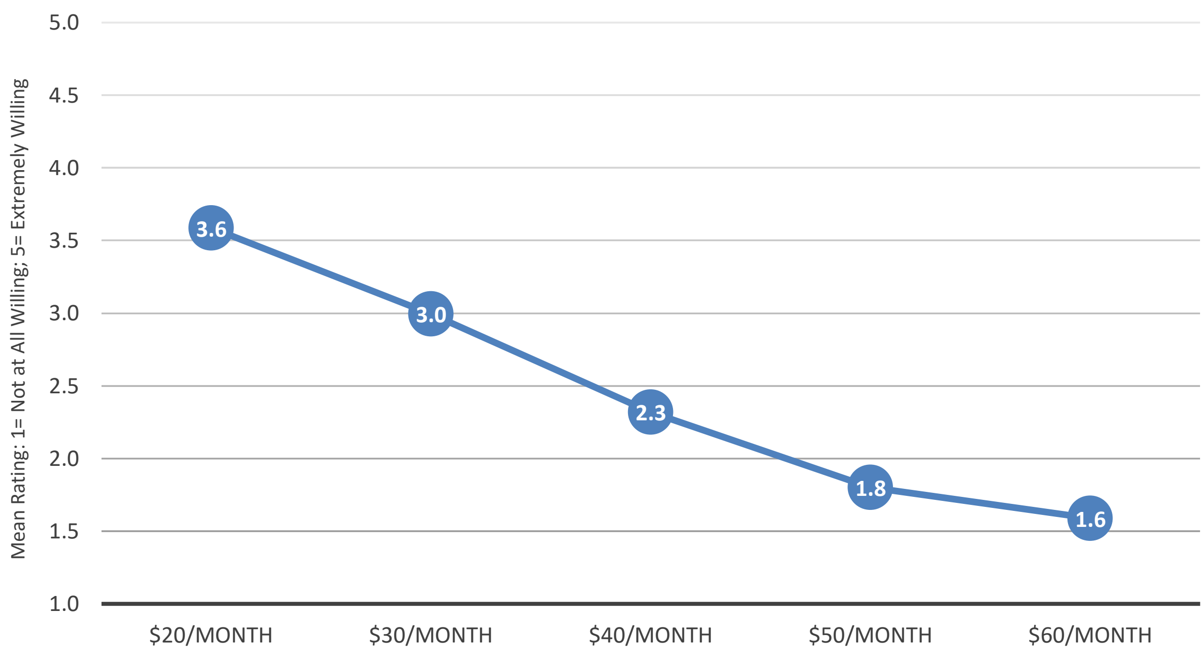
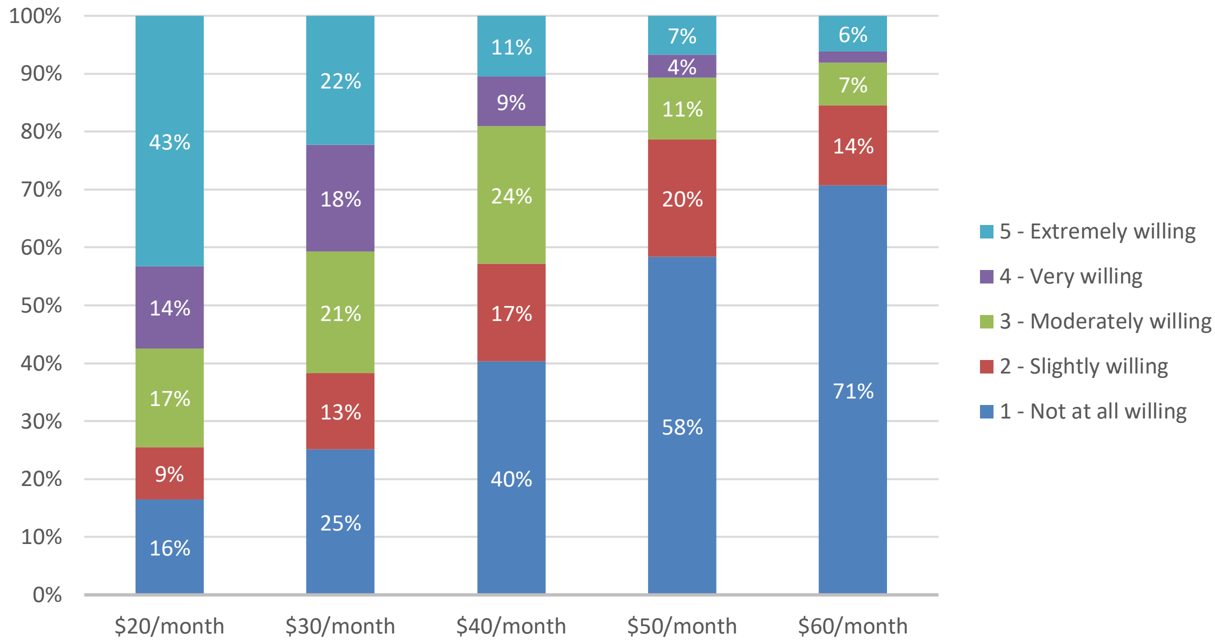
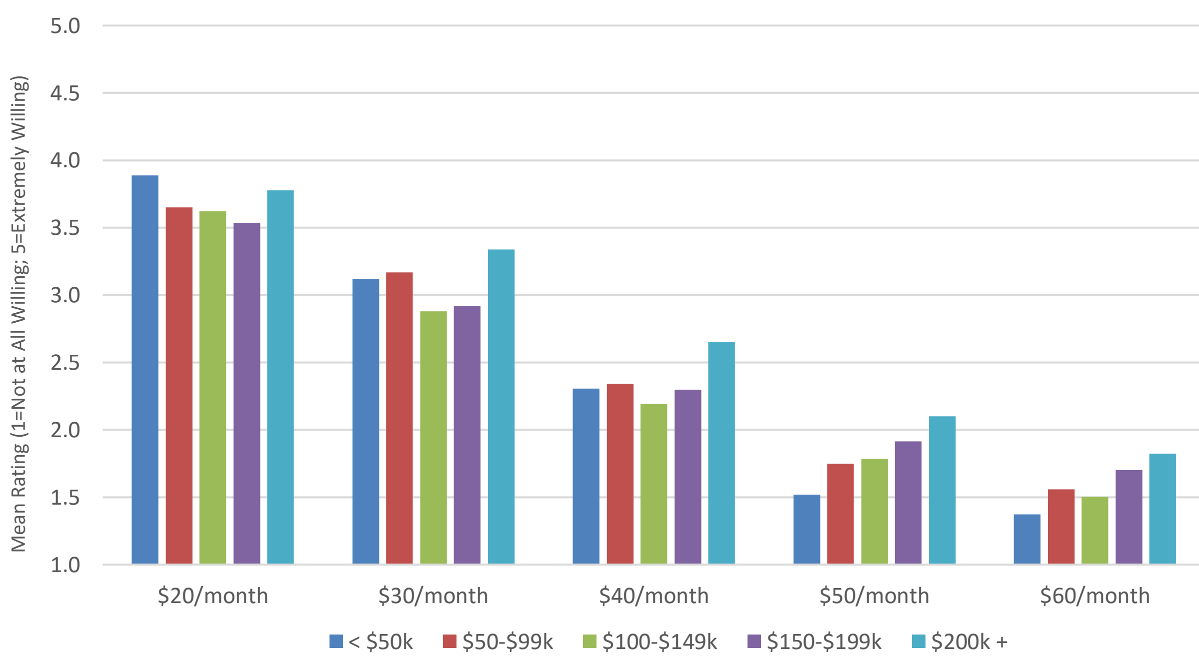


Figure 55: Willingness to pay temporary per-household fee for 10 years



At higher price points, respondents with a household income of $200,000+ would be more willing to pay a per-household fee than would those earning under $50,000 per year (see Figure 56).

Figure 56: Willingness to pay temporary per-household fee for 10 years by income



Respondent opinions about role of City of Cambridge

Respondents were asked their opinions about the City's role in providing or promoting broadband communications services within the area. Figure 57 illustrates the mean ratings, while Figure 58 provides detailed responses to each portion of the question.

Figure 57: Opinions about the role(s) for City of Cambridge (mean ratings)

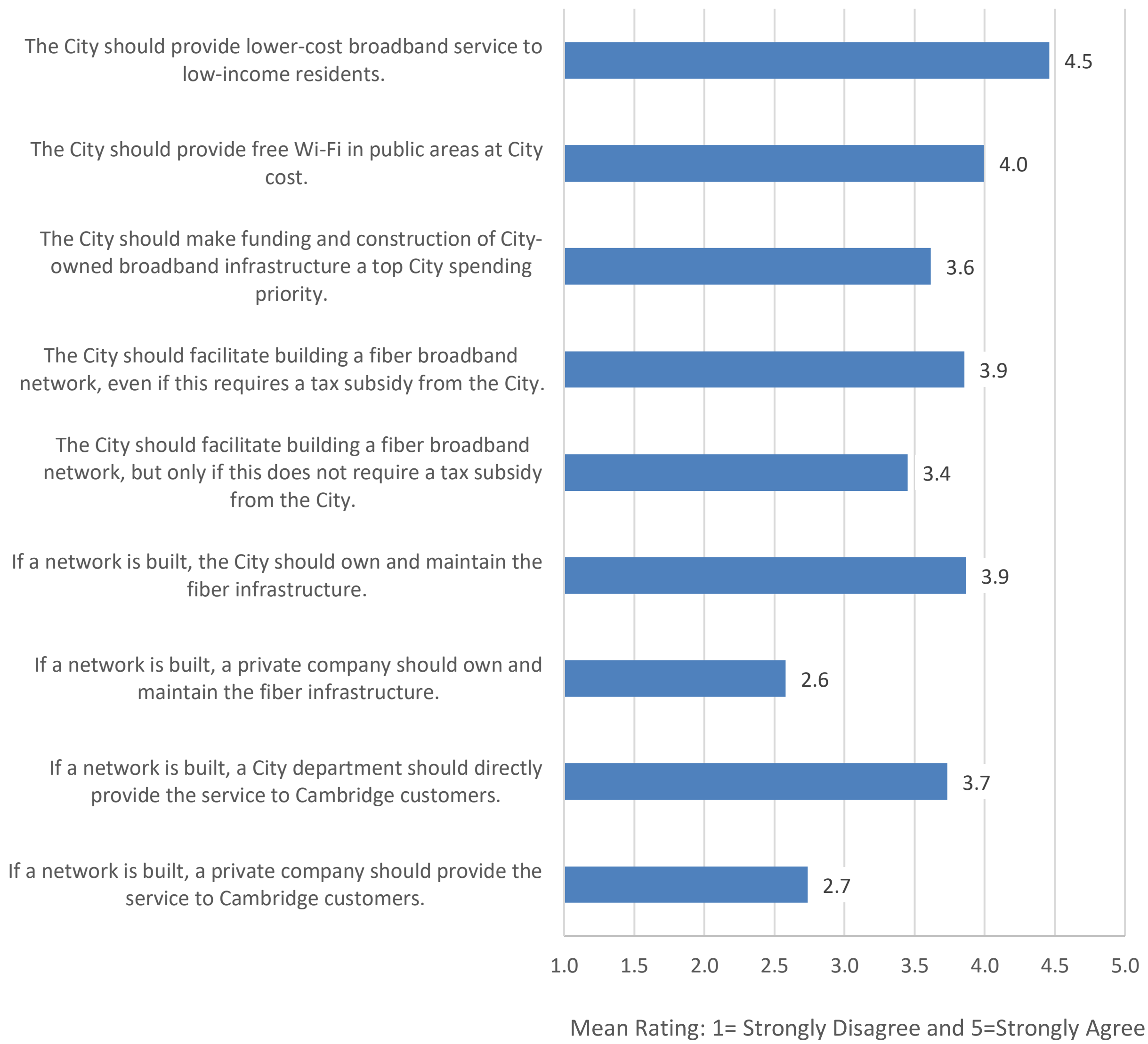
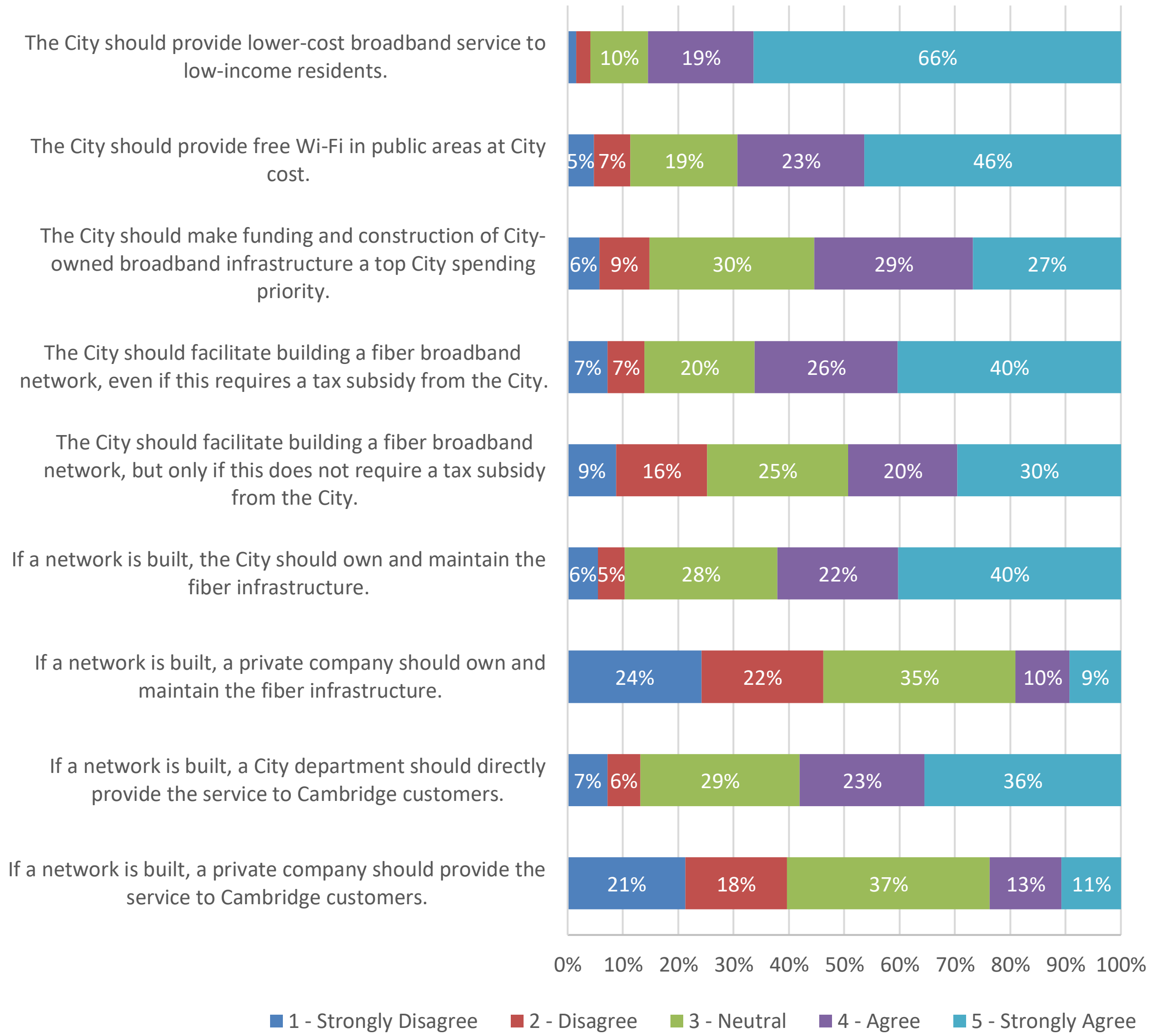


Figure 58: Opinions about the role(s) for City of Cambridge



Overall, there is strong support for the City providing lower-cost broadband service to low-income residents, with two-thirds of respondents strongly agreeing. Additionally, nearly one-half of respondents strongly agreed (46 percent) and 23 percent agreed the City should provide free Wi-Fi in public areas at City cost.

Respondents were less likely to strongly agree (27 percent) the City should making funding and construction of City-owned broadband infrastructure a top City spending priority. Overall, respondents were split on this statement, with another 29 percent agreeing and 30 percent neutral. Just 15 percent of respondents disagreed (9 percent) or strongly disagreed (6 percent).

Two-thirds of respondents agreed (26 percent) or strongly agreed (40 percent) the City should facilitate building a fiber broadband network that allows for high-speed service and competition, even if this requires a tax subsidy from the City. In comparison, one-half agreed (20 percent) or strongly agreed (30 percent), but only if it does not require a tax subsidy from the City.

Respondents were more likely to agree the City over a private company should manage the fiber broadband network if one were built in Cambridge. Specifically, 22 percent of respondents agreed, and 40 percent strongly agreed the City should own and maintain the fiber infrastructure. Just one-fifth agreed (10 percent) or strongly agreed (9 percent) a private company should do so.

Additionally, 23 percent of respondents agreed, and 36 percent strongly agreed the City should directly provide the fiber broadband service to Cambridge customers, while 13 percent agreed, and 11 percent strongly agreed that a private company should do so.

In general, respondents in lower-income households (as well as demographic groups that tend to be lower-income, such as lower-educated and renters, for some statements), were generally more supportive of the City providing broadband internet services, particularly for low-income residents. At the same time, they were less likely than those earning $50,000 or more to agree the City should facilitate building a fiber broadband network even if it requires a tax subsidy from the City (see Figure 59 to Figure 64).

Figure 59: The City should provide lower-cost broadband service to low-income residents

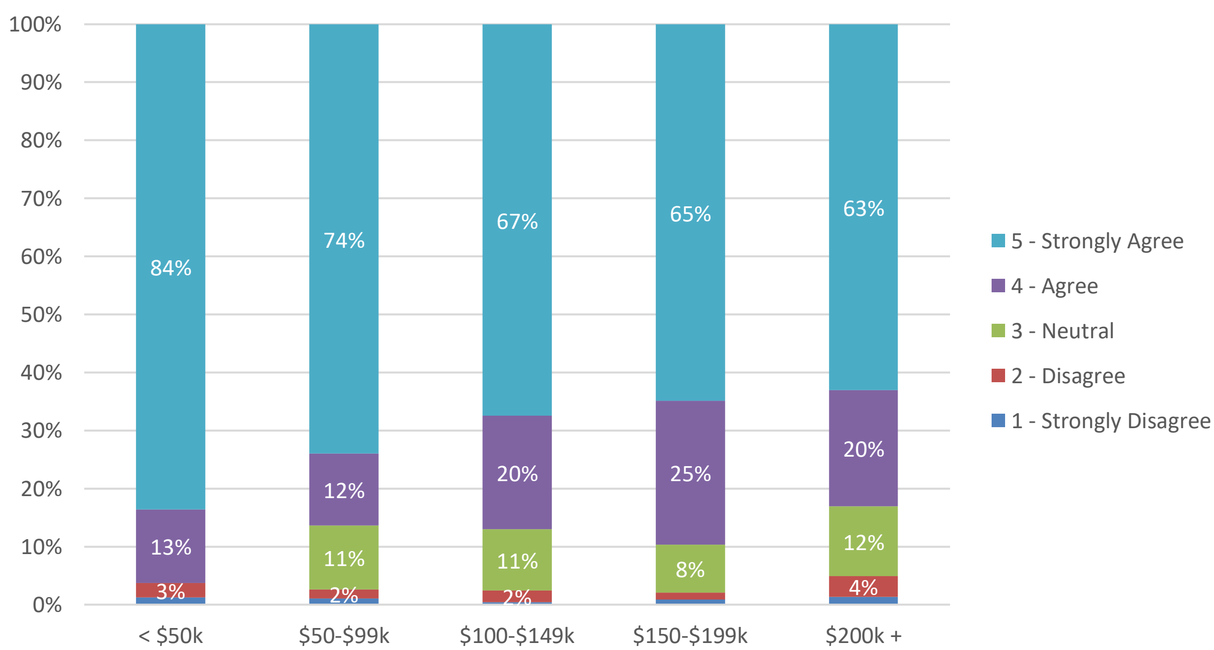


Figure 60: The City should provide free Wi-Fi in public areas at City cost

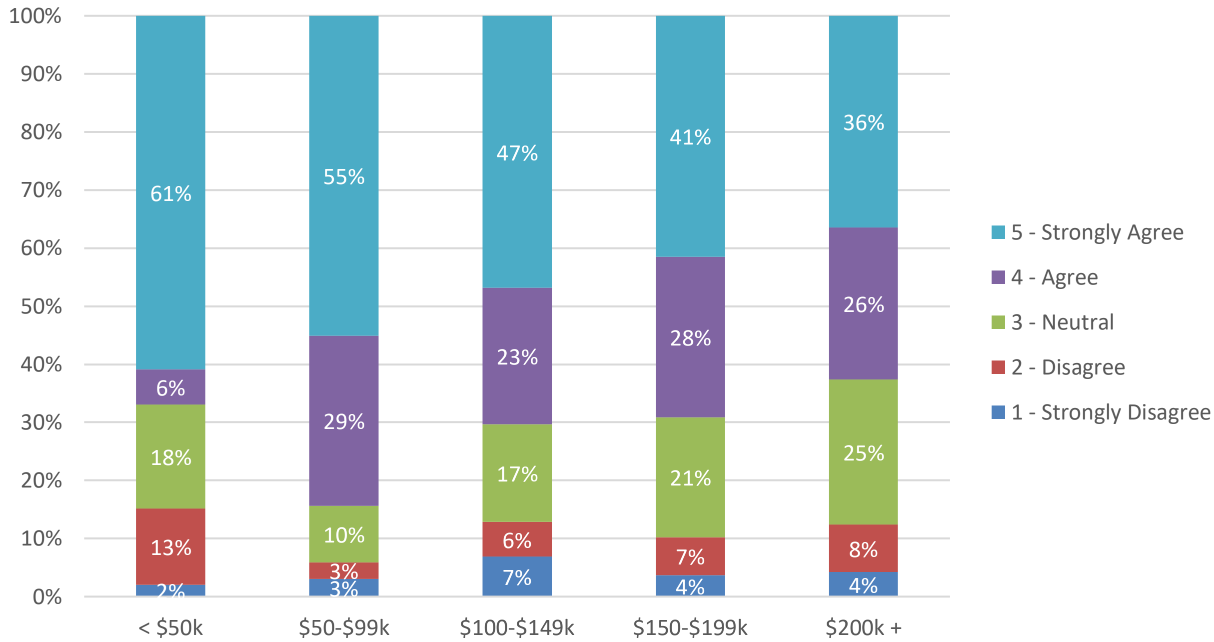


Figure 61: The City should facilitate building a fiber broadband network, even if this requires a tax subsidy from the City

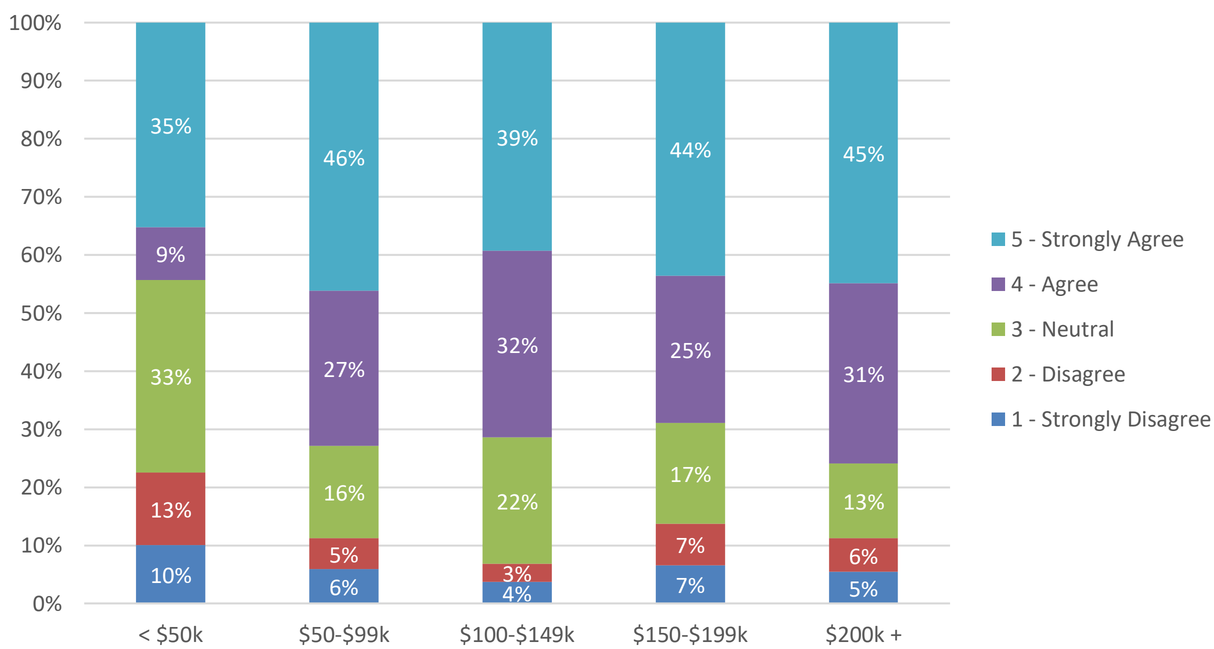


Figure 62: The City should facilitate building a fiber broadband network, but only if this does not require a tax subsidy from the City

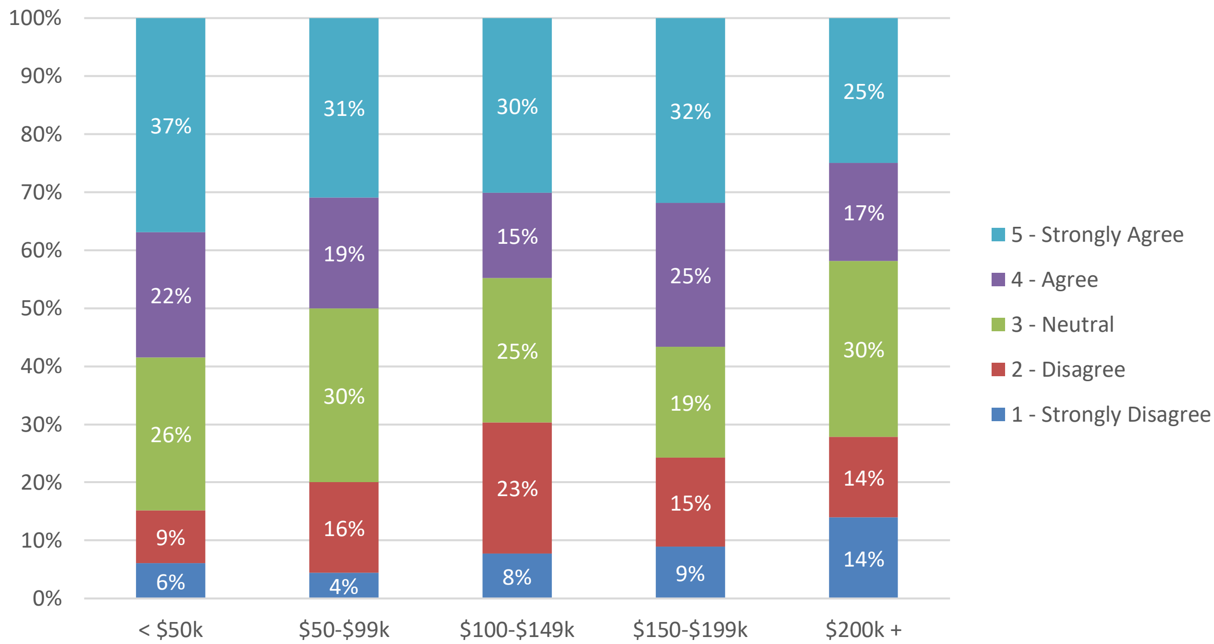


Figure 63: If a network is built, the City should own and maintain the fiber infrastructure

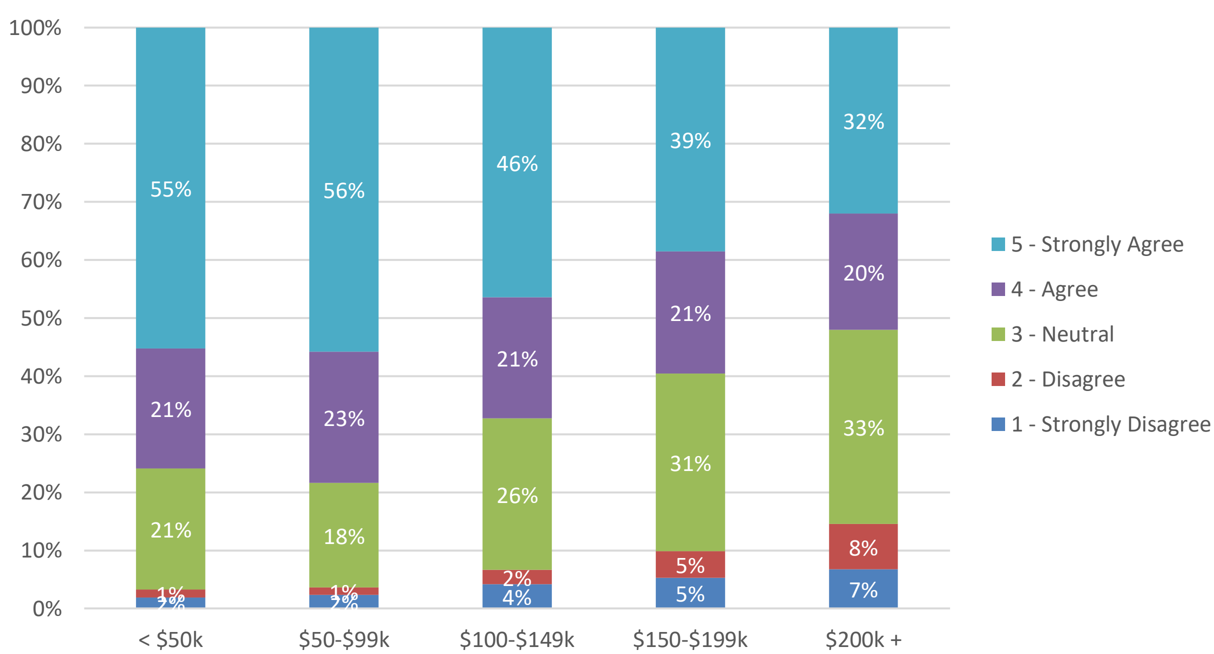
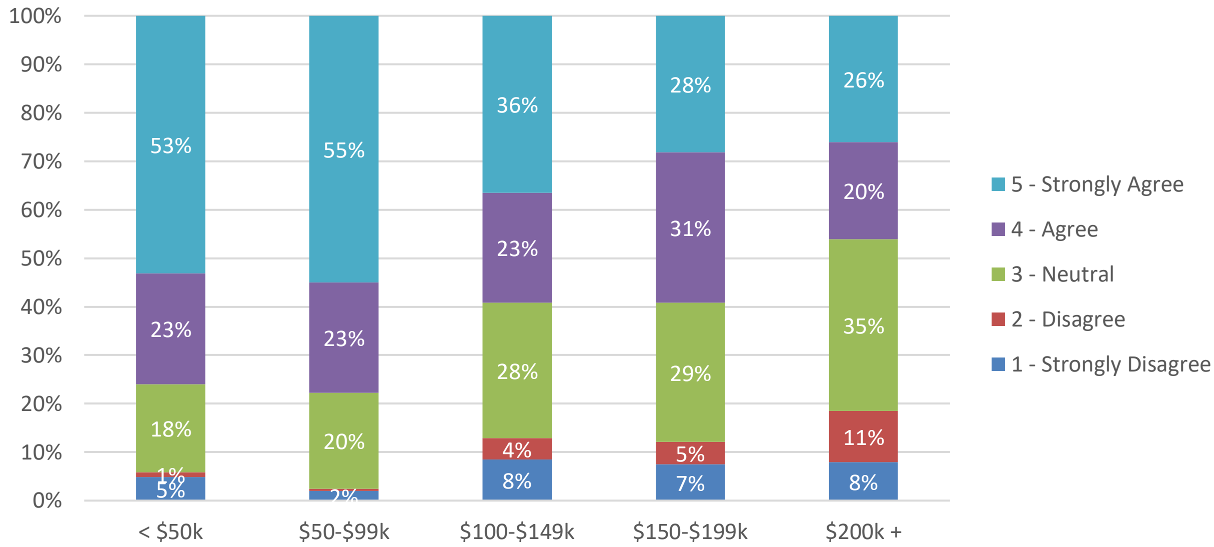
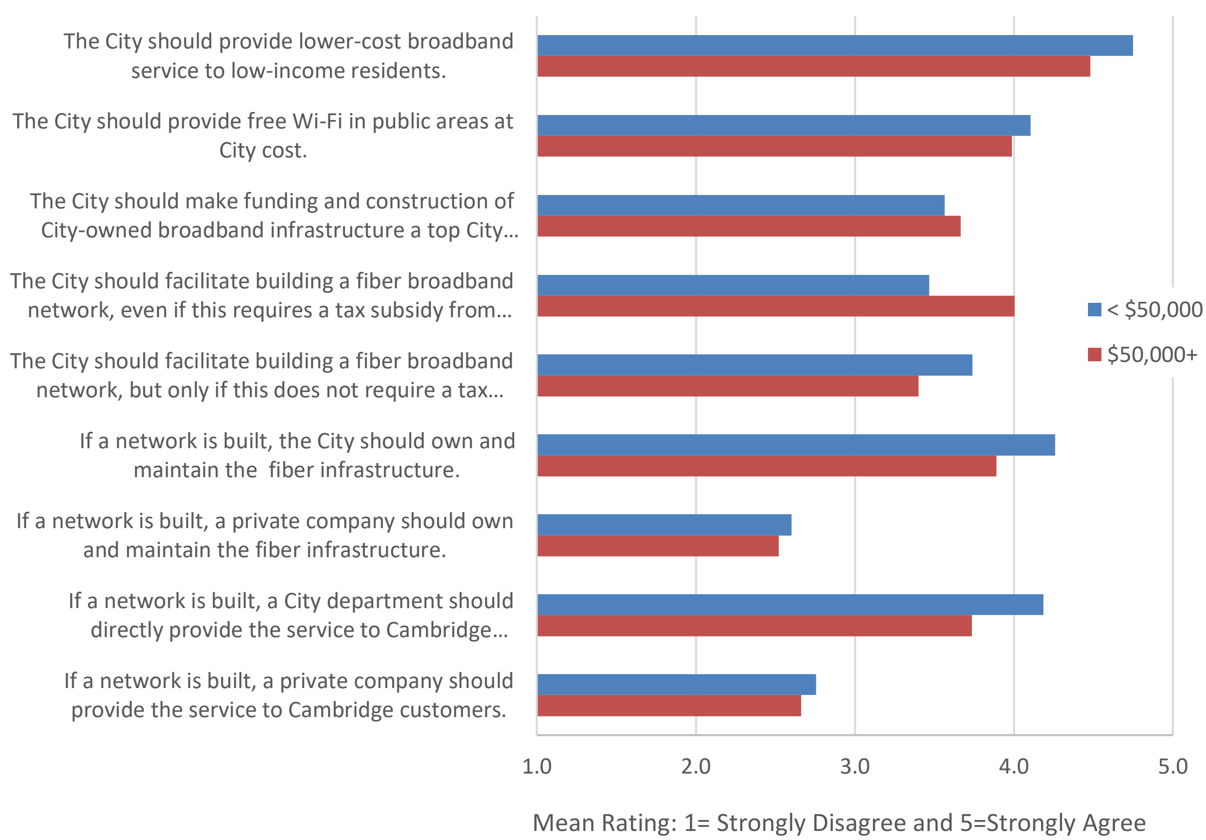


Figure 64: If a network is built, the City should directly provide the Service to customers



Mean ratings for the various statements by household income are illustrated in Figure 65.

Figure 65: Opinions about the role(s) for City of Cambridge by household income



Respondent information

Basic demographic information was gathered from survey respondents and is summarized in this section. Several comparisons of respondent demographic information and other survey questions were provided previously in this report.

As indicated previously in Figure 1 regarding age-weighting, disproportionate shares of survey respondents were in the older age cohorts relative to the City's adult population as a whole. Approximately 21 percent of survey respondents are ages 65 and older, compared with 15 percent of the population. Conversely, only 36 percent of survey respondents are ages 18 to 34, compared with 53 percent of the population (see Figure 66). The weighted survey results presented in this report are adjusted to account for these differences and to provide results that are more representative of the City's population, as discussed previously. The following chart compares the survey age to the age distribution of adults in the population.

Figure 66: Age of respondents and City of Cambridge adult population

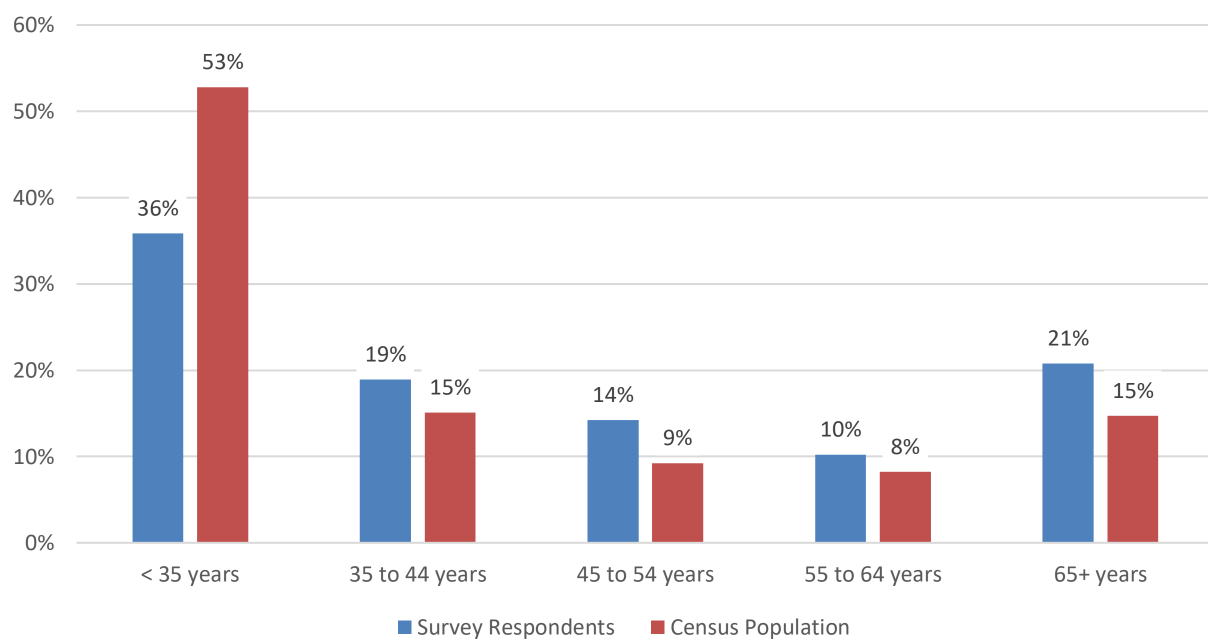


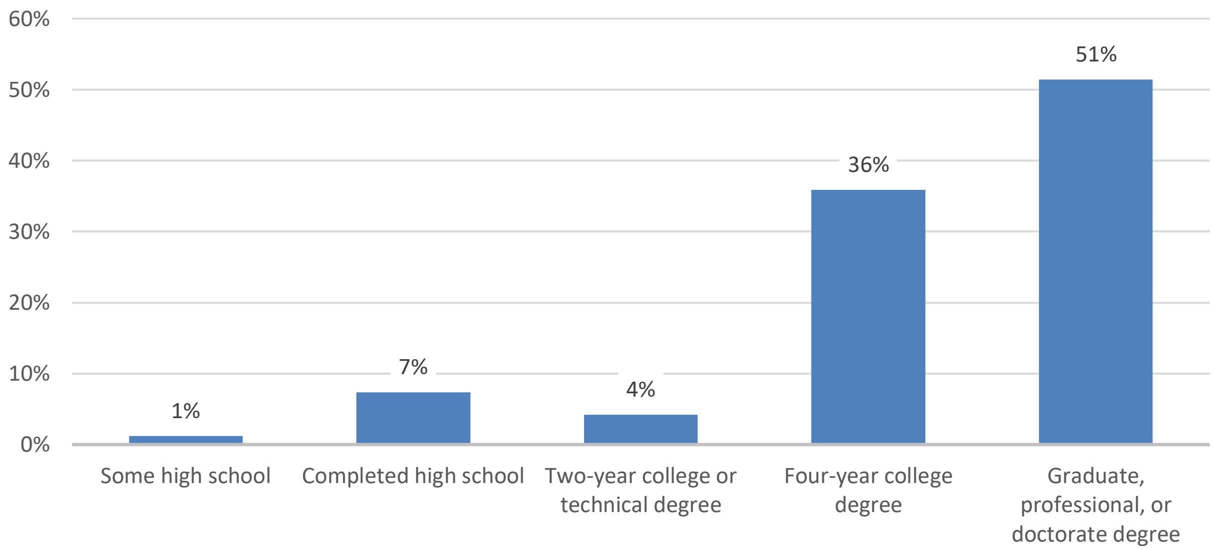
Table 38 highlights the demographic characteristics of survey respondents, broken out by respondent age. Respondents ages 35 to 54 years are more likely than older and younger respondents to have children in the household. Respondents under age 45 are more likely than older respondents to have above a high school education; those under age 35 are somewhat more likely to have a four-year college degree. Younger respondents are also somewhat more likely than others to be Asian/South Asian and more likely to rent their home. Respondents ages 65+ are more likely than other respondents to live alone (55 percent) and to be female (67 percent); they also have a somewhat lower household income.

Table 38: Demographic profile by respondent age

	Age Cohort	< 35	35-44	45-54	55-64	65+	Total
Highest level of education completed	HS education or less	4%	1%	25%	12%	20%	9%
	Two-year college or technical degree	2%	7%	4%	9%	7%	4%
	Four-year college degree	48%	30%	26%	18%	16%	36%
	Grad, professional, or doctorate degree	46%	62%	46%	61%	57%	51%
	Total	*314*	*90*	*55*	*49*	*86*	*594*
Household Income	Less than $50,000	14%	10%	37%	20%	35%	19%
	$50,000 to $99,999	18%	12%	8%	18%	27%	18%
	$100,000 to $149,999	22%	10%	14%	14%	13%	18%
	$150,000 to $199,999	16%	25%	4%	17%	9%	16%
	$200,000 or more	30%	43%	37%	31%	16%	31%
	Total	*286*	*81*	*47*	*45*	*69*	*528*
Race/ethnicity	Hispanic/Latino	10%	5%	12%	11%	8%	9%
	Asian/South Asian, alone	21%	26%	24%	13%	5%	19%
	Black/African American, alone	6%	9%	21%	12%	21%	10%
	White, alone	56%	53%	39%	59%	64%	56%
	Other race/more than one	8%	8%	5%	4%	2%	6%
	Total	*310*	*84*	*53*	*47*	*77*	*578*
Gender identity	Female	46%	39%	49%	49%	67%	49%
	Male	52%	59%	50%	49%	31%	50%
	Non-binary/gender non-conforming	1%	1%	0%	0%	0%	0%
	Self-describe	1%	2%	1%	2%	2%	1%
	Total	*300*	*81*	*51*	*47*	*79*	*566*
Total Household Size (Adults + Children)	One	18%	15%	18%	34%	55%	24%
	Two	53%	41%	32%	41%	37%	46%
	Three	19%	24%	22%	14%	3%	17%
	Four or more	10%	20%	28%	11%	5%	12%
	Total	*315*	*89*	*53*	*47*	*83*	*594*
Children in household	No Children in HH	94%	66%	48%	93%	95%	86%
	Children in HH	6%	34%	52%	7%	5%	14%
	Total	*315*	*89*	*53*	*47*	*83*	*594*
Own/rent residence	Own	6%	46%	59%	62%	63%	30%
	Rent	94%	54%	41%	38%	37%	70%
	Total	*314*	*90*	*54*	*48*	*83*	*595*
Number of years lived at current residence	Less than 1 year	27%	14%	9%	6%	3%	18%
	1 to 2 years	41%	21%	9%	8%	3%	27%
	3 to 4 years	17%	16%	12%	6%	6%	14%
	5 or more years	16%	49%	70%	81%	88%	41%
	Total	*315*	*89*	*54*	*47*	*83*	*595*

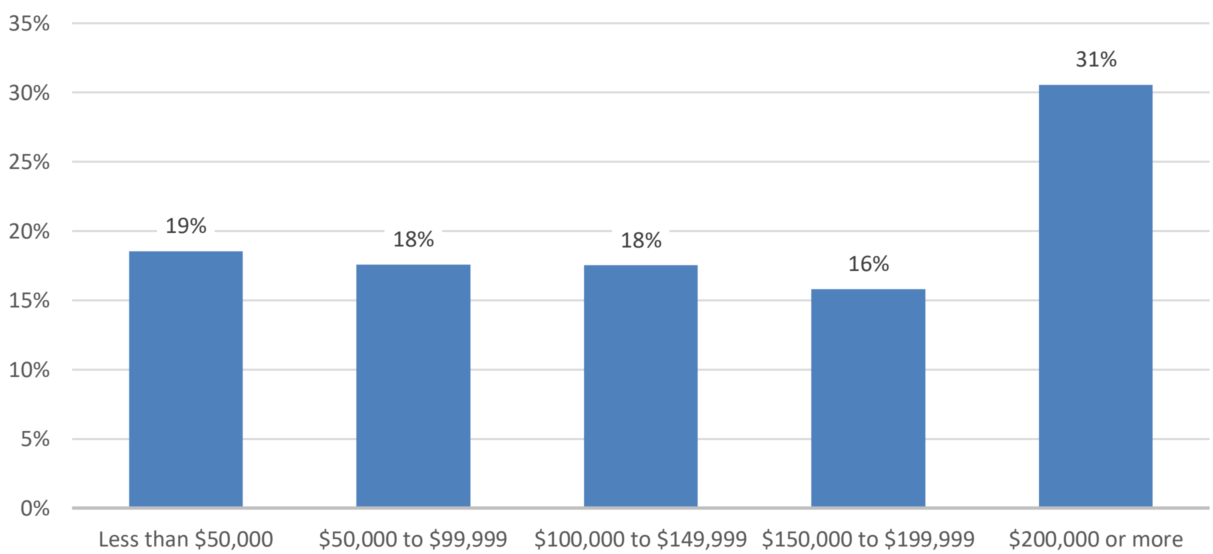
The respondents' highest level of education attained is summarized in Figure 67. Most respondents have a four-year college degree (36 percent) or a graduate, professional, or doctorate degree (51 percent).

Figure 67: Education of respondent



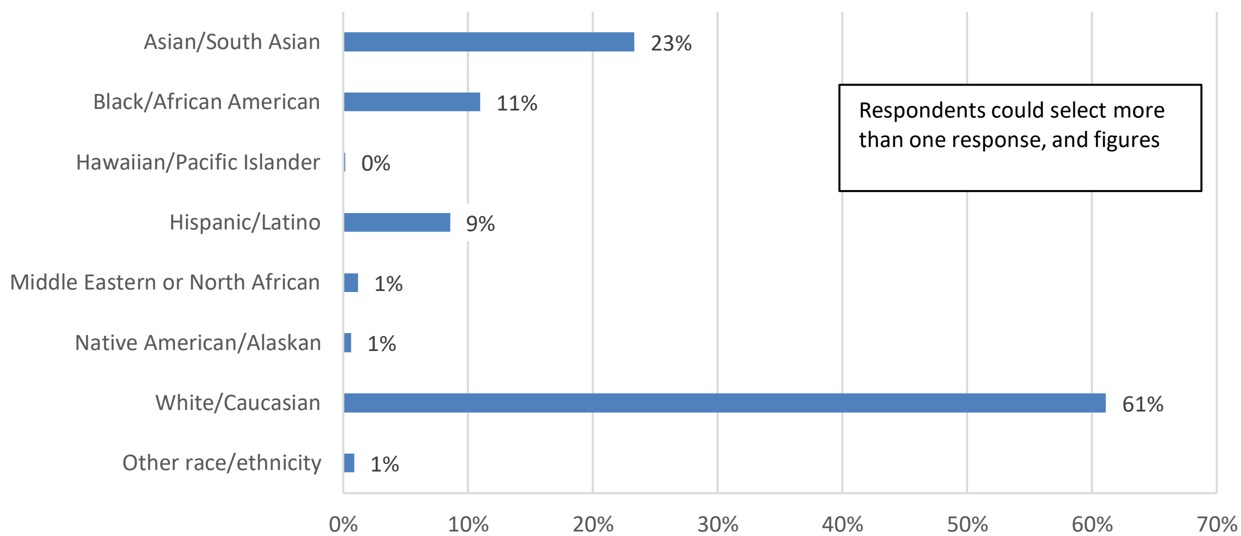
One-fifth of respondents earn under $50,000 per year, and 61 percent earn over $50,000 per year (see Figure 68).

Figure 68: Annual household income



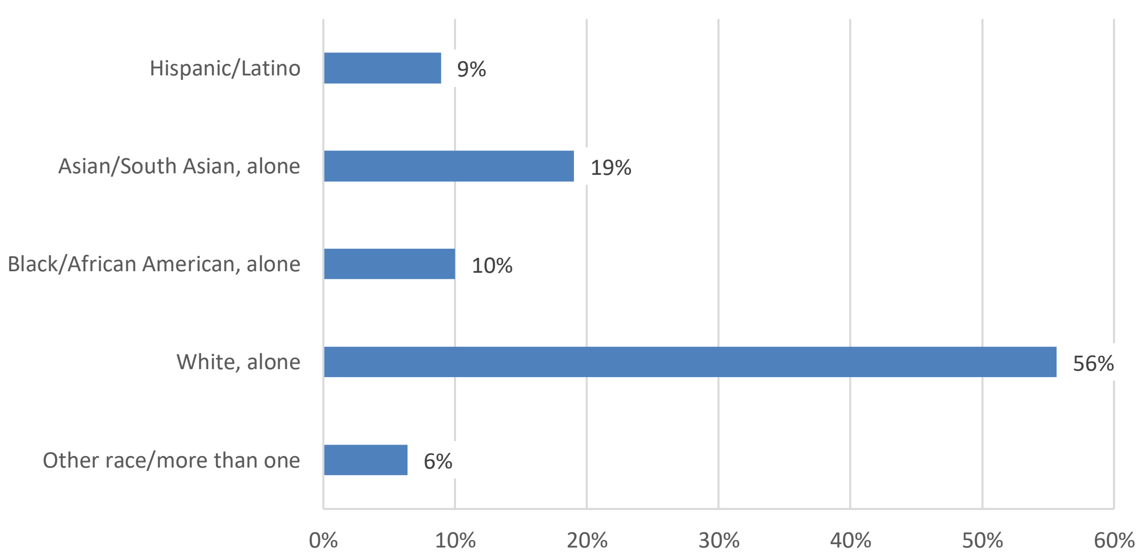
As illustrated in Figure 69, 61 percent of the weighted sample of respondents are White/Caucasian. Nearly one-fourth (23 percent) of respondents are Asian/South Asian, 11 percent are Black/African American, and 9 percent are Hispanic/Latino.

Figure 69: Race/ethnicity



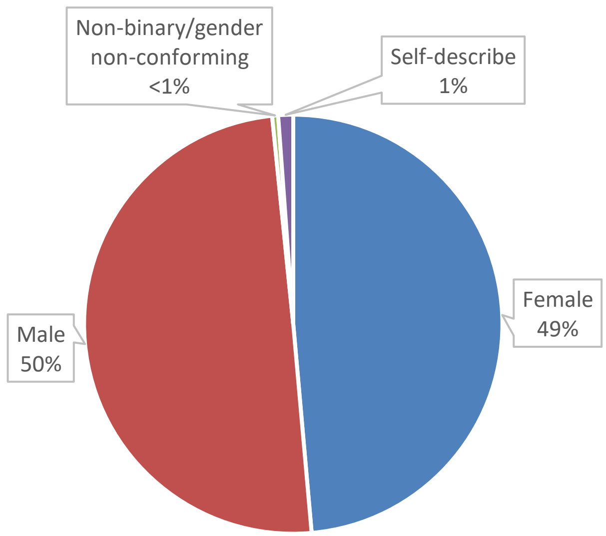
Responses to the race/ethnicity question were also grouped to correspond as closely as possible to U.S. Census categories. These categories were used in weighting the survey data by race and ethnicity. Overall, 9 percent of the weighted sample of respondents are Hispanic/Latino (of any race). Another 19 percent of respondents are Asian/South Asian, alone (not Hispanic/Latino), 10 percent are Black/African American, alone, and 56 percent are White, alone (see Figure 70).

Figure 70: Race/ethnicity grouped



The sample was split almost equally between males and females (see Figure 71). Few respondents identified as non-binary/gender non-conforming or self-described their gender identity.

Figure 71: Gender identity



Respondents were asked to indicate the number of adults and children in their household. Nearly one-half of households have two members, and 29 percent have three or more members. Just 25 percent of respondents live alone (see Figure 72). More than one-fourth of respondents have children living in the household (see Figure 73).

Figure 72: Total household size

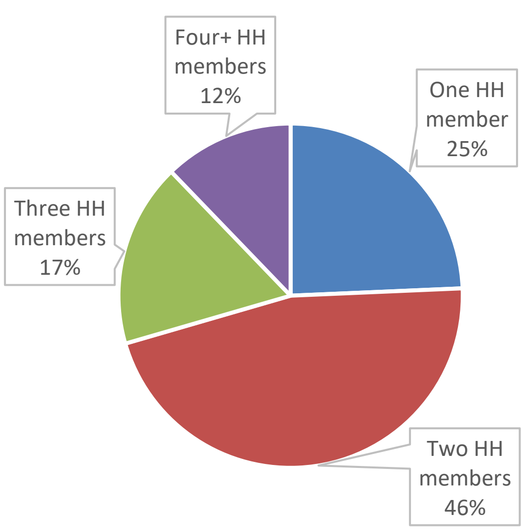
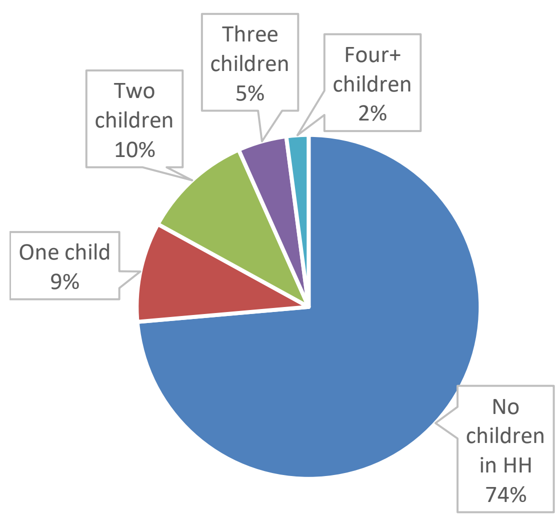
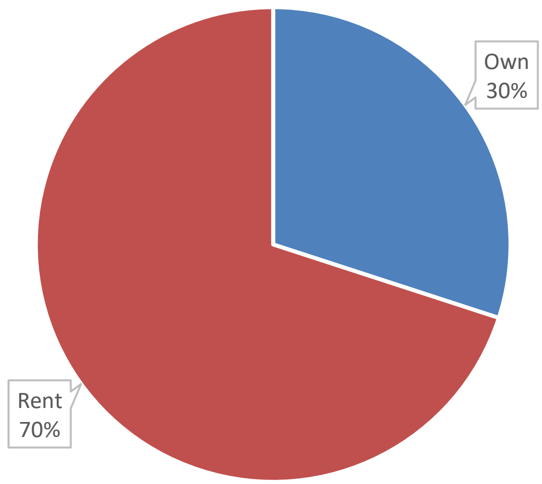


Figure 73: Number of children in household



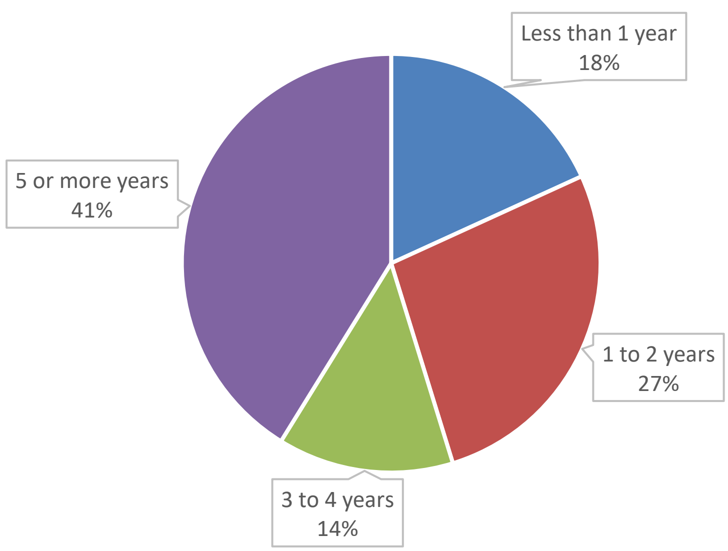
Most respondents (70 percent) rent their residence, while 30 percent own their home (see Figure 74).

Figure 74: Own or rent residence



Four in 10 respondents have lived at their current residence for five or more years. Another 41 percent have resided at the home for one to four years, while 18 percent have lived at the residence for less than one year (see Figure 75).

Figure 75: Number of years lived at current residence



Appendix C: Current state of broadband service, pricing, and competition in Cambridge

Overview of residential broadband providers

Leaving aside satellite providers and exclusively mobile providers, the four leading residential fixed broadband providers in Cambridge are as follows, according to the survey and FCC data. (With respect to large companies and institutions in Cambridge, those willing to pay premium prices have robust options for obtaining enterprise-grade services from fiber providers.)

Comcast is the dominant provider. Because the City negotiated buildout requirements in its cable franchise agreement with Comcast (and the predecessor owners of the cable system), high-speed residential internet service is available everywhere in the City. Comcast offers service of up to 1.2 Gbps download, 35 Mbps upload, but has recently announced that it may upgrade service around the country with new technology that would enable the company to provide symmetrical Gigabit service. In late 2022, the company said it will start offering "multi-gig symmetrical services to customers before the end of 2023."[19] The announcement did not specify which markets might be so served, and the industry has a history of making announcements of test results that do not quickly translate into widespread commercial deployments. Comcast has made no announcements respecting Cambridge in particular.

Market share: The survey conducted for this report in the summer of 2022 found that 80 percent of households are Comcast subscribers.

Starry, a startup company that emerged in the past several years, offers fixed-wireless service in parts of Cambridge. Starry is also offering fiber-to-the-premises (FTTP) service in certain buildings that host Starry's rooftop base station equipment. (This is because at such buildings, Starry pulls fiber into the building and therefore has a direct wired connection to units in that building.) In early 2022, the Cambridge Housing Authority (CHA) announced a partnership with Starry to provide broadband service to more than 2,630 of its units located throughout 27 communities in Cambridge.[20] Starry filed for Chapter 11 bankruptcy protection in February 2023 but a company representative said Starry is committed to continuing to serve areas already covered by its infrastructure expanding market share within those areas.

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[19] "Inside the Nation's Largest and Fastest Multi-Gig Network Deployment," Comcast, Press Release, Sept. 8, 2022, https://corporate.comcast.com/press/releases/comcast-expand-evolve-wifi-largest-multi-gigabit-network.

[20] "Starry Expands its Ultra-Low-Cost Broadband Access Program to the Cambridge Housing Authority," CHA, News Release, Jan. 27, 2022, https://cambridge-housing.org/starry-expands-its-ultra-low-cost-broadband-access-program-to-the-cambridge-housing-authority/.

Market share: The survey conducted by CTC for this study indicated that 8 percent of Cambridge households are Starry subscribers, making it the second most used provider in the City after Comcast.

Verizon provides slow DSL service through legacy phone lines, but at speeds far below broadband. However, in the past two years it has begun offering some residences a much faster fixed wireless service leveraging its mobile network. Verizon also provide its Fios fiber service a number of newly constructed apartment buildings in East Cambridge and elsewhere, showing that the company will opportunistically provide fiber service in Cambridge, even though it has not announced any broad fiber expansion plans.

Market share: Verizon market share may be reflected in one or more of the following: 3 percent of respondents said they used a fiber service, 2 percent of survey respondents reported they use DSL service, 1 percent said they use mobile networks, and 2 percent said they use "other."

NetBlazr is similar to Starry in offering fixed-wireless service to some buildings where it can get permission to install rooftop receivers and establish a line-of-sight from their transmitters. Within the building, internal wiring is used. In response to a 2015 RFP issued by the CHA, NetBlazr serves two CHA developments, the Millers' River apartments on Lambert Street and the Roosevelt Towers mid-rise on Cambridge Street.

Market share: Less than 1 percent of survey respondents reported that they use NetBlazr service.

Recent changes in Comcast service offerings reflect gradual network upgrades and reduced promotional gigabit pricing

In January of 2023 CTC reviewed prices and service plans offered by Comcast. Using the same addresses checked as part of CTC's digital equity study in 2020, we noted that Comcast had reduced its 24-month promotional prices on 1 Gbps services (from $79.99 to $70) but that the post-promotional price had risen slightly to $112.

Comcast has also increased the speeds of its entry-level offering, now 400 Mbps download, 10 Mbps upload, with a promotional price of $30 for the first 24 months,[21] rising to $102 thereafter. Comcast also increased download speeds of this entry-level plan. In 2020, Comcast offered just 5 Mbps upload on its entry-level plans.

The offerings were consistent across neighborhoods.

Actual prices paid can be far higher if the consumer has selected bundled services and an initial promotional period has ended. And some consumers who may be eligible and have applied for the company's Internet Essentials program for eligible low-income consumers pay just $10 or $30

[21] One-year contract required.

per month—depending on the speed—or $0 if they pair Internet Essentials with the $30 subsidy available under the Affordable Connectivity Program.

Table 39 shows Comcast's advertised speeds for internet-only plans in our initial analysis, conducted in 2020, which is provided here as a frame of reference. Table 39 shows the offerings as of January 2023.

Table 39: Comcast's advertised service plans in Cambridge (2020)

Package	Internet speed	Monthly price	Notes
Performance Starter	25/5 Mbps	$49.95	No term agreement required; pricing does not include a router. Regular rate is $54.95/month.
Performance Internet	100/5 Mbps	$77.95	No term agreement required; pricing does not include a router.
Performance Pro	200/5 Mbps	$39.99 for the first 12 months, then $92.95	No term agreement required; pricing does not include a router. Regular introductory rate is $49.99/month for the first year. $39.99 rate reflects $10/month discount for enrolling in automatic payments and paperless billing; discount is available for the first 24 months.
Blast! Internet (with one-year term agreement)	300/10 Mbps	$59.99 for the first 24 months, then $97.95	One-year term agreement required; pricing does not include a router. Regular introductory rate is $69.99/month for the first 24 months. $59.99 rate reflects $10/month discount for enrolling in automatic payments and paperless billing; discount is available for the first 24 months.
Blast! Internet (with no term agreement)	300/10 Mbps	$69.99 for the first 12 months, then $97.95	No term agreement required; pricing does not include a router. Regular introductory rate is $79.99/month for the first 12 months. $69.99 rate reflects $10/month discount for enrolling in automatic payments and paperless billing; discount is available for the first 24 months.
Extreme Pro Internet (with one-year term agreement)	600/15 Mbps	$69.99 for the first 24 months, then $102.95	One-year term agreement required; pricing does not include a router. Regular introductory rate is $79.99/month for the first 24 months. $69.99 rate reflects $10/month discount for enrolling in automatic payments and paperless billing; discount is available for the first 24 months.
Extreme Pro Internet (with no term agreement)	600/15 Mbps	$79.99 for the first 12 months, then $102.95	No term agreement required; pricing does not include a router. Regular introductory rate is $89.99/month for the first 12 months. $79.99 rate reflects $10/month discount for enrolling in automatic payments and paperless billing; discount is available for the first 24 months.

Package	Internet speed	Monthly price	Notes
Gigabit (with two-year term agreement)	1,000/35 Mbps	$79.99 for the first 24 months, $89.99 for months 25-36, then $107.95	Two-year term agreement required; pricing does not include a router. Regular introductory rate is $89.99/month for the first 36 months. $79.99 rate reflects $10/month discount for enrolling in automatic payments and paperless billing; discount is available for the first 24 months.
Gigabit (with no term agreement)	1,000/35 Mbps	$89.99 for the first 12 months, then $107.95	No term agreement required; pricing does not include a router. Regular introductory rate is $99.99/month for the first 12 months. $89.99 rate reflects $10/month discount for enrolling in automatic payments and paperless billing; discount is available for the first 24 months.
Gigabit Pro	2/2 Gbps	$299.95	Two-year term agreement required; pricing does not include a router.

Table 40: Comcast's advertised service plans in Cambridge (January 2023)

Package	Internet speed[22]	Monthly price	Notes
Fast	400/10 Mbps	$30 per month for the first 24 months, then $102 per month	One-year term contract required. Pricing includes $10 per month paperless billing and autopay discount, which continues past the promotional period; standard price after 24 months is $102. Router not included; xFi Gateway router is $15 per month, and xFi Complete router is $20 per month for the first 12 months and then reverts to regular pricing (currently $25).
Superfast	800/20 Mbps	$60 per month for the first 24 months, then $107 per month	No term contract required. Pricing includes $10 per month paperless billing and autopay discount, which continues past the promotional period; standard price after 24 months is $107. Router not included; xFi Gateway router is $15 per month, and xFi Complete router is $20 per month for the first 12 months and then reverts to regular pricing (currently $25).
Gigabit	1,000/20 Mbps	$70 per month for the first 24 months, then $112 per month	No term contract required. Pricing includes $10 per month paperless billing and autopay discount, which continues past the promotional period; standard price after 24 months is $112. Router not included; xFi Gateway router is $15 per month, and xFi Complete router is $20 per month for the first 12 months and then reverts to regular pricing (currently $25).
Gigabit Extra	1,200/35 Mbps	$80 per month for the first 24 months, then $117 per month	No term contract required. Pricing includes $10 per month paperless billing and autopay discount, which continues past the promotional period; standard price after 24 months is $117. Router not included; xFi Gateway router is $15 per month, and xFi Complete router is $20 per month for the first 12 months and then reverts to regular pricing (currently $25).

Verizon DSL speeds are still low, but the company offers Fios fiber service in a growing number of newer apartment developments

CTC also reviewed plans and pricing from Verizon in January and February 2023 and compared them to data collected in 2020 for the City's digital equity study. Verizon offers a very slow DSL service (3 Mbps download or less) in Cambridge for $40 plus a required phone service for $34.99, for a total of $74.99 (see Table 41).

[22] Upload speeds were provided by a Comcast customer service representative

Table 41: Verizon residential DSL plan in Cambridge

Package	Internet speed	Monthly price	Notes
DSL internet	1.1 – 3 Mbps	$40 for internet service; $74.99 with required phone add-on	No annual contract is required; pricing does not include a router ($99 one-time fee)

According to FCC data from June 2022, Verizon also reports very limited fiber coverage in the city. While checking for service at various sites in Cambridge, CTC identified that Verizon Fios internet services are available at several new apartment and condominium developments (see Table 42). Most are located in East Cambridge around Kendall Square and the Cambridge Crossing mixed-use development project, and three are located elsewhere.

Table 42: Developments in Cambridge offered Verizon Fios service

Building name	Address
Sierra and Tango Condominiums	1 Earhart Street/2 Earhart Street
Elevate	1 Leighton Street
Park 151[23]	151 North First Street
Zinc	22 Water Street
Third Square Apartments	285 Third Street/303 Third Street
Watermark Kendall West and Watermark Kendall East	350 Third Street/250 Kendall Street
Tempo Cambridge Apartments	201 Concord Turnpike/203 Concord Turnpike
Vox on Two Apartments	223 Concord Turnpike
Atmark	80 Fawcett Street/90 Fawcett Street

Developments were offered the plans and pricing for Verizon Fios service shown in Table 43 (as of February 2023).

[23] Verizon's retail interface offered Fios internet service to multiple units in this building; however, a Verizon company representative indicated that Verizon did not have Fios service on record at this location.

Table 43: Verizon Fios plans in Cambridge

Internet speed	Monthly price	Notes
300/300 Mbps	$49.99	No contract, two-year price guarantee; router included
500/500 Mbps	$69.99	No contract, three-year price guarantee; router included
Up to 940/880 Mbps	$89.99	No contract, four-year price guarantee; router with Whole Home Wi-Fi included

NetBlazr and Starry offer consistent pricing and higher upload speeds, but availability is limited

The pricing tiers of NetBlazr's and Starry's service are simple and clear and offer higher upload speeds than Comcast. Table 44 shows NetBlazr's pricing and speed tiers, including its lower pricing for eligible low-income consumers.

Table 44: NetBlazr services and monthly pricing

Service offering	Pricing	Monthly price reflecting low-income discount
500/500 Mbps (requires ethernet wiring in building)	$60 (or $50 per month if customer makes one-time $600 annual payment)	$40
200/200 Mbps	$40	$20
100/100 Mbps (building with Cat 3 wiring)	$40	$20

A Starry representative indicated in November 2022 that the company offers the plans shown in Table 45 where service is available, with the same pricing across all markets. The company's standard plan is 200/100, which is available across all buildings Starry serves. Higher speed tiers—the Pro and Gigabit plans—are only available if supported by a building's internal wiring. The 100/50 and 30/30 plans are only available at facilities participating in Starry Connect, which includes the Cambridge Housing Authority.

Table 45: Starry services and pricing (2022)

Service offering	Monthly price
Starry Gigabit 1,000/500	$80
Starry Pro 500/250	$65
Starry Plus 200/100	$50
Starry Select 100/50	$30
Low-Cost Plan (Starry Connect) 30/30 Mbps	$15

Verizon and T-Mobile now offer fixed wireless residential services to some Cambridge households

Verizon and T-Mobile have also begun to leverage their 5G networks to offer residential fixed wireless service in some areas of Cambridge. These 5G-based networks' actual performance characteristics can vary widely, depending upon the frequencies available to the location, line-of-sight issues, and network congestion during peak times, but they do represent a new competitive dimension to the Cambridge residential broadband market.

Some of these providers have been quick to claim that their 5G networks will be capable of speeds of up to 1 Gbps,[24] but industry reports and press have regularly challenged these claims.[25] This highest level of performance is only possible using one of the three different radio spectrum frequency ranges composing mobile providers' 5G networks. High-band, millimeter wave (MMW) frequencies can offer data transfer speeds of 1 Gbps in ideal conditions but "cannot travel far, cannot travel well through buildings, and tend to be absorbed by trees and rain."[26] As

[24] E.g., 5G Speed: How Fast is 5G?," Verizon, August 3, 2020, https://www.verizon.com/about/our-company/5g/5g-speed-how-fast-is-5g; T-Mobile Dominates in New 5G Studies and Advances 5G with Carrier Aggregation," T-Mobile, January 18, 2022, https://www.t-mobile.com/news/network/t-mobile-dominates-in-new-5g-studies-and-advances-5g-with-carrier-aggregation; Igal Elbaz, "BREAKING NEWS: AT&T 5G Network First in the U.S. to Surpass 1 Gigabit Wireless Speeds," AT&T, Technology Blog, March 29, 2019, https://about.att.com/innovationblog/2019/03/1_gigabit_wireless_speeds.html.

[25] E.g., Geoffrey A. Fowler, "The 5G Lie: The Network of the Future is Still Slow," *The Washington Post*, September 8, 2020, https://www.washingtonpost.com/technology/2020/09/08/5g-speed/; "United States' Mobile and Fixed Broadband Internet Speeds," Ookla, https://www.speedtest.net/global-index/united-states#market-analysis, accessed April 26, 2022.

[26] Congressional Research Service, "Fifth-Generation (5G) Telecommunications Technologies: Issues for Congress," p. 15, January 30, 201, ("CRS 5G Report").

a result, using this portion of the spectrum effectively requires that MMW-capable small cell transmitters be placed on every city block.

Targeted, block-by-block deployments are required to use the full potential of 5G, so 5G networks could exacerbate the digital divide, rather than helping to close it.[27] MMW's inability to penetrate walls and windows can often require that antennas outside of buildings be used to distribute the signal inside.[28] In this way, MMW deployments may increasingly resemble the fixed wireless offerings of companies like Starry, requiring that mobile service providers develop a dense network of MMW transmitters and receiver antennas outside dwellings to offer real fixed broadband services to residences.

In contrast with MMW spectrum, the low- and mid-band frequencies used in 5G networks offer propagation and transmission characteristics more closely resembling existing 4G LTE systems. These low- and mid-band 5G have improved mobile broadband network performance noticeably, but nonetheless fall well short of both 5G maximum performance claims and fixed broadband service providers' higher service tiers.

Unfortunately, the major mobile providers' maps do not necessarily distinguish between 5G high-band MMW coverage and the low- and mid-band 5G service availability primarily offered by the carriers. As a result, interested consumers must read about these fixed wireless offerings closely, contact service representatives about the likely service speeds in their areas, and may ultimately experience bandwidth limitations that are particular to their individual locations.

Verizon

Verizon's fixed wireless residential offering leverages its mobile network to provide home broadband service at advertised speeds starting at 85 Mbps download, 10 Mbps upload. The company announced in August of 2022 that this service was newly available in parts of Boston and Springfield.[29] A Verizon representative said that a number of Cambridge households can also obtain the service.

We found that five of the 12 addresses we checked in January 2023 were now being offered the fixed-wireless plan. The plan comes with caveats: during times of network congestion, the residential fixed-wireless speeds may be throttled. Still, this service represents another option

[27] E.g., Zack Quaintance, "Does 5G Have the Potential to Make the Digital Divide Worse?," *Government Technology*, January 31, 2020, https://www.govtech.com/network/does-5g-have-the-potential-to-make-the-digital-divide-worse.html; Ari Breland, "Experts Worry 5G Could Widen Digital Divide in Cities," *The Hill*, September 30, 2018, https://thehill.com/policy/technology/409047-experts-worry-5g-could-widen-digital-divide/?rl=1.

[28] "T-Mobile High Speed 5G Internet Gateway (Nokia 5G21) External Antenna Guide," Waveform, April 25, 2022, https://www.waveform.com/a/b/guides/hotspots/t-mobile-5g-gateway.

[29] Boston and Springfield get new Internet options from Verizon, the network America relies on | About Verizon

for some Cambridge residents. And for those with certain existing Verizon wireless mobile phone plans, the residential add-on can cost as little as $25 per month.

Table 46 shows the fixed wireless services offered in Cambridge; as noted, not all households can get the fixed wireless service.

Table 46: Verizon residential fixed-wireless plans

Package	Internet speed	Monthly price	Notes
5G Home	85-300 Mbps download, up to 10 Mbps upload	$60 or $50 with autopay; $25 per month with AutoPay if paired with an existing mobile plan	No contract, two-year price guarantee, router included
5G Home Plus	300-1,000 Mbps download, up to 50 Mbps upload[30]	$80 or $70 with autopay	No contract, three-year price guarantee; router included; price includes Verizon Cloud Unlimited service ($19.99 per month value)

T-Mobile

T-Mobile offers two residential internet plans: Home Internet, which offers typical speeds between 33-182 Mbps download, 6-23 Mbps upload,[31] and Home Internet Lite, which is offered in some areas where Home Internet service is not yet available. The Lite plan offers the same speeds with a choice of four data caps and higher pricing overall. Home Internet Lite customers may also experience lower speeds during times of network congestion "due to data prioritization."[32]

5G Home Internet was available at nine out of 14 Cambridge addresses checked in February 2023. For the five addresses not offered service, T-Mobile's retail interface indicated that the Home

[30] Verizon advertises these speeds for customers with the 5G Internet Gateway or Verizon Receiver (utilizing 5G Ultra Wideband high-band); customers with the Verizon Internet Gateway or Verizon Receiver (utilizing 5G Ultra Wideband mid-band) will receive the same speeds as the 5G Home plan. "Important Plan Information," Verizon Wireless, https://www.verizon.com/support/important-plan-information/ (accessed January 17, 2023).
[31] "Frequently Asked Questions," T-Mobile, https://www.t-mobile.com/home-internet/faq (accessed February 21, 2023).
[32] "T-Mobile Home Internet Lite," T-Mobile, https://www.t-mobile.com/support/home-internet/t-mobile-home-internet-lite (accessed February 21, 2023).

Internet Lite plan might be available; a sales representative was unable to confirm whether the Lite plan was available at two of these addresses.

According to a T-Mobile representative, T-Mobile Home Internet has the same cost, fees, and allowances for every address it serves. Table 47 shows available T-Mobile plans and pricing; these plans are not available at all addresses in Cambridge.

Table 47: T-Mobile residential fixed wireless plans

Package	Internet speed	Monthly price	Notes
Home Internet (unlimited)	Typical speeds between 33-182 Mbps download, 6-23 Mbps upload	$55	$5 monthly discount with AutoPay. Unlimited data, no caps, no overage penalties. No equipment fees, installation fees or activation fees; no contract.
Home Internet Lite (100 GB data cap)	Typical speeds between 33-182 Mbps download, 6-23 Mbps upload	$55	$5 monthly discount with AutoPay. One-time $35 assisted support or device connection charge; speeds of 128 Kbps after data allowance.
Home Internet Lite (150 GB data cap)	Typical speeds between 33-182 Mbps download, 6-23 Mbps upload	$80	$5 monthly discount with AutoPay. One-time $35 assisted support or device connection charge; speeds of 128 Kbps after data allowance.
Home Internet Lite (200 GB data cap)	Typical speeds between 33-182 Mbps download, 6-23 Mbps upload	$105	$5 monthly discount with AutoPay. One-time $35 assisted support or device connection charge; speeds of 128 Kbps after data allowance.
Home Internet Lite (300 GB data cap)	Typical speeds between 33-182 Mbps download, 6-23 Mbps upload	$155	$5 monthly discount with AutoPay. One-time $35 assisted support or device connection charge; speeds of 128 Kbps after data allowance.

Appendix D: Survey instrument

Cambridge, Massachusetts

Internet Demand Survey

LITERIS ANTIQVIS NOVIS INSTITVTIS DECORA
CIVICO REGIMINE DONATA A.D.1846
CANTABRIGIA

May 2022

Even if you do not have home internet service, please complete the relevant portions of this survey form and return to us. Your opinions, experiences, and information are important to us.

If you need help completing this survey in your language, please email lgianetti@cambridgema.gov or call 617-349-3317.

The City of Cambridge is sending you this survey as part of its research into the adequacy of internet service and choice in Cambridge. *The information gathered will not be used to sell you anything.* Even if you do not have internet access at your home, please complete the relevant portions of this survey. We value your input.

How long will the survey take?
This survey should take approximately 10 minutes to complete.

What is the due date to complete the survey?
Please return your completed form in the enclosed postage-paid envelope by **June 24, 2022**.

What if I have questions about the survey?
If you have questions regarding this survey, please contact Lee Gianetti, director of communications, at 617-349-3317 or send an email to lgianetti@cambridgema.gov.

Thank you in advance for your participation!

COMMUNICATION SERVICES

1. **Which of the following services do you currently purchase for your household or personal use?** *(✓ all that apply)*

   - [1] Internet service in my home (excluding cellular/mobile)
   - [2] Cellular/mobile telephone service with internet (smartphone)
   - [3] Cellular/mobile telephone service without internet (basic phone)
   - [4] Fixed (land line) telephone service
   - [5] Cable or satellite television **(Please answer** Question 2**)**
   - [6] Don't know
   - [7] None of the above

2. **How likely are you to cancel your cable or satellite TV service in the next 12 months and watch TV shows and movies online?**

   - [1] Not at all likely
   - [2] Slightly likely
   - [3] Moderately likely
   - [4] Very likely
   - [5] Extremely likely

3. **How many personal computing devices (desktop/laptop computers, tablets, smartphones) do you have in your home?**

   - [1] 1 or 2
   - [2] 3 or 4
   - [3] 5 or more
   - [4] I do not have any personal computing devices in my home

4. What is your primary home internet service connection? *(✓ only one)*

- [1] No home internet service **(Please skip to** Question 9**)**
- [2] Telephone line (dial-up)
- [3] Digital Subscriber Line or DSL (Verizon or other)
- [4] Cable modem (from Comcast)
- [5] Satellite (from DirecTV, Dish Network, or HughesNet, etc.)
- [6] Cellular/mobile internet (smartphone, mobile Wi-Fi hotspot)
- [7] Fiber-optic connection (Verizon or other)
- [8] Fixed wireless service from NetBlazr
- [9] Fixed wireless service from Starry
- [10] Other (Please specify: ________________________)

5. How important are the following aspects of your primary *home* internet service if you have or were to purchase broadband internet service? *(please circle your response for each aspect, where 1=Not at all important, 2=Slightly important, 3=Moderately important, 4=Very important, 5=Extremely important)*

Aspect	*Not at all important*				*Extremely important*
(a) Speed of connection	1	2	3	4	5
(b) Reliability of connection	1	2	3	4	5
(c) Price of services	1	2	3	4	5
(d) Overall customer service	1	2	3	4	5
(e) Ability to "bundle" with TV and phone (not applicable if your primary home connection is a smartphone)	1	2	3	4	5

6. **How satisfied are you with the following aspects of your current *home* internet service?** *(please circle your response for each aspect, where 1=Not at all satisfied, 2=Slightly satisfied, 3=Moderately satisfied, 4=Very satisfied, 5=Extremely satisfied)*

Aspect	*Not at all Satisfied*				*Extremely Satisfied*
(a) Speed of connection	1	2	3	4	5
(b) Reliability of connection	1	2	3	4	5
(c) Price of services	1	2	3	4	5
(d) Overall customer service	1	2	3	4	5
(e) Ability to "bundle" with TV and phone (not applicable if your primary home connection is a smartphone)	1	2	3	4	5

7. **Please estimate how much your household pays PER MONTH for your PRIMARY home service, regardless of provider and regardless of whether the service is internet-only or a bundle.**

- [1] $0 to $20
- [2] $21 to $40
- [3] $41 to $60
- [4] $61 to $80
- [5] $81 to $100
- [6] $101 to $120
- [7] $121 to $140
- [8] $141 to $160
- [9] $161 to $180
- [10] $181 to $200
- [11] $201 to $220
- [12] $221 to $240
- [13] $241 to $260
- [14] $261 to $280
- [15] $281 to $300
- [16] More than $300

8. **Is the fee in Question 7 part of a bundled package (purchased together with cable TV or phone service)?**

- [1] It's for three services: internet, cable TV and phone
- [2] It's for two services: internet and cable TV
- [3] It's for two services: internet and phone
- [4] It's for internet-only service (no cable TV or phone)

OPINIONS ABOUT INTERNET SERVICE

9. **Would you like to see an additional internet service provider come to Cambridge?**

   1 Yes
   2 No
   3 Not sure

10. **If Cambridge had an additional internet service provider, how likely would you be to acquire services from the new provider?**

    1 Not at all likely
    2 Slightly likely
    3 Moderately likely
    4 Very likely
    5 Extremely likely

11. **If Cambridge had an additional internet service provider, how important would it be to you that this provider also offer video and phone services?**

    1 Not at all important
    2 Slightly important
    3 Moderately important
    4 Very important
    5 Extremely important

12. How willing would you be to purchase, from a new Cambridge fiber internet service provider, service of 100 Mbps per second download/100 Mbps per second upload (not including bundled services such as video or phone) at the following prices? As a frame of reference, Comcast's 100 Mbps download service has an upload speed of 10 Mbps. *(please circle your response at each price level, where 1=Not at all willing, 2=Slightly willing, 3=Moderately willing, 4=Very willing, 5=Extremely willing)*

Monthly Price	*Not at all Willing*				*Extremely willing*
(a) $30 per month	1	2	3	4	5
(b) $50 per month	1	2	3	4	5
(c) $70 per month	1	2	3	4	5
(d) $90 per month	1	2	3	4	5
(e) $110 per month	1	2	3	4	5

13. **How willing would you be to purchase, from a new Cambridge internet service provider, service of 1 Gigabit per second download/1 Gigabit per second upload (not including bundled services such as video or phone) at the following prices? This is ten times the speed mentioned in the previous question and can handle multiple high-definition video streams simultaneously or transmit large video files near-instantaneously. As a frame of reference, Comcast's 1.2 Gigabit download speed service comes with an upload speed of 35 Mbps.** *(please circle your response at each price level, where 1=Not at all willing, 2=Slightly willing, 3=Moderately willing, 4=Very willing, 5=Extremely willing)*

Monthly Price	*Not at all Willing*				*Extremely willing*
(a) $30 per month	1	2	3	4	5
(b) $50 per month	1	2	3	4	5
(c) $70 per month	1	2	3	4	5
(d) $90 per month	1	2	3	4	5
(e) $110 per month	1	2	3	4	5

14. **One way to make subscription costs more affordable is for the City to impose a temporary city-wide tax assessment to help spread the initial construction cost of a new fiber optic broadband network over a longer period (e.g., ten years). How willing would you be to pay a temporary per-household fee at the following hypothetical levels?** *(please circle your response at each price level, where 1=Not at all willing, 2=Slightly willing, 3=Moderately willing, 4=Very willing, 5=Extremely willing)*

Monthly Additional Fee	*Not at all willing*				*Extremely willing*
(a) $20 per month for ten years	1	2	3	4	5
(b) $30 per month for ten years	1	2	3	4	5
(c) $40 per month for ten years	1	2	3	4	5
(d) $50 per month for ten years	1	2	3	4	5
(e) $60 per month for ten years	1	2	3	4	5

15. **Please indicate to what extent you disagree or agree that the City of Cambridge should do the following:** *(please circle your response for each statement, where 1=Strongly Disagree, 2=Disagree, 3=Neutral, 4=Agree, 5=Strongly Agree)*

Aspect	*Strongly Disagree*				*Strongly Agree*
(a) The City should facilitate building a fiber broadband network that allows for high-speed service and competition, even if this requires a tax subsidy from the City.	1	2	3	4	5
(b) The City should facilitate building a fiber broadband network that allows for high-speed service and competition, but only if this does not require a tax subsidy from the City.	1	2	3	4	5
(c) The City should provide lower-cost broadband service to low-income residents.	1	2	3	4	5
(d) If a network is built, the City should own and maintain the fiber infrastructure.	1	2	3	4	5
(e) If a network is built, a private company should own and maintain the fiber infrastructure.	1	2	3	4	5
(f) If a network is built, a City department should directly provide the service to Cambridge customers.	1	2	3	4	5
(g) If a network is built, a private company should provide the service to Cambridge customers	1	2	3	4	5
(h) The City should provide free Wi-Fi in public areas at City cost.	1	2	3	4	5
(i) The City should make funding and construction of City-owned broadband infrastructure a top City spending priority.	1	2	3	4	5

INFORMATION ABOUT YOU

The following questions will help describe the total group of survey respondents. Your individual information will not be reported separately—it will be reported only as a part of a larger group to help ensure that the respondents are a representative sample of the residents of the City of Cambridge.

16. Which of the following best describes your age?

- 1 Under 18
- 2 18 to 24 years
- 3 25 to 34 years
- 4 35 to 44 years
- 5 45 to 54 years
- 6 55 to 64 years
- 7 65 to 74 years
- 8 75 years and older

17. What is the highest level of education you have completed?

- 1 Some high school
- 2 Completed high school
- 3 Two-year college or technical degree
- 4 Four-year college degree
- 5 Graduate, professional, or doctorate degree

18. What is your approximate annual household income?

- 1 Less than $25,000
- 2 $25,000 to $49,999
- 3 $50,000 to $74,999
- 4 $75,000 to $99,999
- 5 $100,000 to $149,999
- 6 $150,000 to $199,999
- 7 $200,000 or more
- 8 Prefer not to answer

19. What is your ethnicity? *(✓ all that apply)*

- [1] Asian/South Asian
- [2] Black/African American
- [3] Hawaiian/Pacific Islander
- [4] Hispanic/Latino
- [5] Middle Eastern or North African
- [6] Native American/Alaskan
- [7] White/Caucasian
- [8] Other (please enter)____________________

20. What is your gender identity?

- [1] Female
- [2] Male
- [3] Non-binary/gender non-conforming
- [4] Self-describe (please enter) ________________________
- [5] Prefer not to answer

21. How many people reside in your home (adults and children)?

Adults (including yourself)	Children age 18 and younger
[1] 1	[0] None
[2] 2	[1] 1
[3] 3	[2] 2
[4] 4 or more	[3] 3
	[4] 4 or more

22. Do you own or rent your residence?

- [1] Own
- [2] Rent

23. How long have you lived at your current address?

- [1] Less than 1 year
- [2] 1 to 2 years
- [3] 3 to 4 years
- [4] 5 or more years

Thank you for completing this survey!

Appendix E: Massachusetts Municipal Light Plants

A Municipal Light Plant or MLP is a Massachusetts legal entity that enables a municipality to directly run an electricity, gas or (more recently) telecommunications company—that is, a broadband company. Creating a Cambridge MLP would be required if the City wished to directly run a broadband business, as with Business Model 1. According to legal guidance received by the City, the City does not need an MLP to borrow funds to build a network that would be operated by a partner that would, in turn, provide broadband service.[33] Establishing an MLP is not a prerequisite for building a fiber network; Cambridge built fiber in the past for municipal purposes without an MLP.

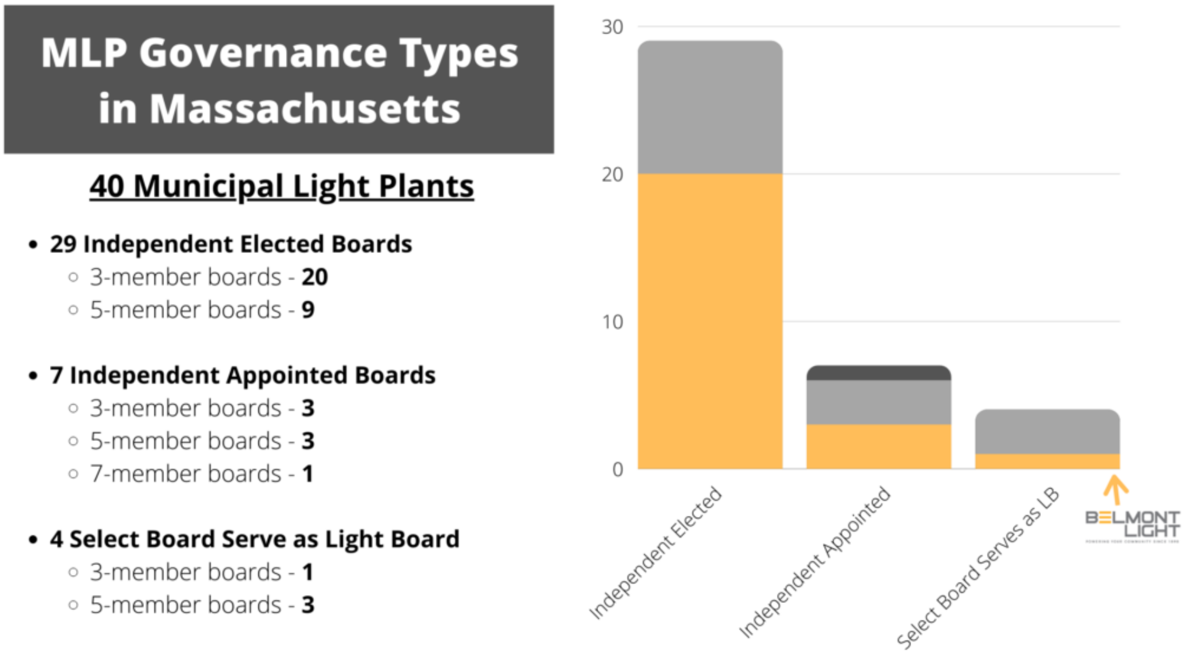
In terms of the mechanics of setting up an MLP, neither CTC nor Rebel provides legal advice; the City should consult with qualified counsel if considering this approach. But we can provide an overview of the process involved. If Cambridge wished to establish an MLP, it would require authorization by a two-thirds vote of the City Council, passed twice in two consecutive years, and then ratification by a majority of voters at an annual special election.

Massachusetts has 40 longstanding MLPs that operate municipal electric utilities. A subset of these—Norwood is one nearby example—entered the cable broadband business in recent decades, leveraging utility expertise and assets to expand into broadband. In addition to these 40 municipal electric utilities, certain rural western Massachusetts towns created MLP structures solely to provide broadband service using one-shot state capital grants. Some formed MLPs and contracted with the Westfield municipal utility's broadband business, Whip City Fiber, to operate the network and provide service. (See Section 5.3.1 for more details on this case.)

MLPs have three general governance types. The majority of the 40 municipal electric utilities operate separately from the municipality; they are governed by independently elected boards who hire and oversee the MLP general manager. However, some fall under tighter municipal control in that the Select Board (in the case of Towns) also acts as the municipal light board, or the governing board is appointed by the municipal manager. Figure 76 shows municipal electric utility MLP governance types in Massachusetts, using information compiled by the Belmont Light Department in 2020. Please note that this table refers only to the actual municipal electric utilities (not the newer broadband-only MLPs in western Massachusetts) and is provided only for informational purposes to illustrate of the types of potential MLP governing models in use in Massachusetts.

[33] Neither CTC nor Rebel provide legal advice; we recommend continued consultation with qualified counsel with respect to any legal requirements associated with constructing a network or operating a broadband business.

Figure 76: Governance types of the 40 municipal electric utilities in Massachusetts[34]



[34] This information was compiled in 2020 and is subject to change. Figure is from publicly available Belmont Light Department resources.