Feasibility Report for a Community Network

Falmouth, Massachusetts

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CCG CONSULTING

Falmouth EDIC | Economic Development & Industrial Corporation

Charles F. Tontar
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Summary of Findings

The Falmouth Economic Development and Industrial Corporation (EDIC) is the primary agency responsible for developing increased economic opportunities for the Town of Falmouth, Massachusetts. The Falmouth Community Network Committee (Network Committee) is a citizens group in Falmouth focused on providing the people in Falmouth with locally controlled internet service. Both the EDIC and the Network Committee believe that a robust broadband infrastructure is critical to the Town of Falmouth's economic growth. In 2019, the Network Committee approached the EDIC with the idea of doing a first ever study of Falmouth's broadband infrastructure. The EDIC agreed and retained CCG to analyze Falmouth's broadband infrastructure and make recommendations regarding the viability of a new, alternative, broadband network that would address gaps in the current system and provide capacity for future growth

CCG found that broadband customers in Falmouth experience inconsistent speeds and frequent outages and that as many as 61% of residents and many businesses would consider moving to a new broadband network. With that level of potential demand, CCG determined that it would be financially feasible to build and operate a new high-speed fiber optic network that would bring gigabit broadband capability to every home and business in Falmouth.

This new fiber network would eliminate the slowdowns and interruptions in internet service that many homes experienced during the pandemic. It will also have the capacity to accommodate future growth for broadband services as more people work from home on the Cape; as business demand for uploading data continues; and as health care providers, schools, and community institutions continue to provide more internet-based services in a post-pandemic world.

This Summary of Findings references the more detailed study that follows and that discusses the various topics and key findings in more detail.

Broadband is Not as Good as it Should Be

Broadband in Falmouth is not as good as it should be. Consider the following:

Comcast Download Speeds. The Comcast network is not delivering the speeds that customers are paying for. As part of the study, we asked the public to take a speed test and the results surprised us. 43% of Comcast customers showed download speeds under 100 Mbps (megabits per second), with 23% of customers getting download speeds under 50 Mbps. This surprised us because we've studied other Comcast markets where the large majority of customers are receiving speeds equal or greater than the subscribed speeds. When asked, Comcast advertises the basic speed in Falmouth as 'up to 150 Mbps". We also heard in the broadband survey that the biggest complaint about Comcast was inconsistent speeds that vary throughout the day with intermittent outages (Page 38).

There are a few possible explanations for the slow speeds. We know that the Comcast network has been updated to the newest DOCSIS 3.1 standard since we found some customers able to buy Comcast's gigabit product. The most likely reason for the slow speeds is that the Comcast network configuration has not been modernized. Comcast purchased this network from Adelphia and much of the original network design from Adelphia is likely still in place. This means that there might still be large neighborhood nodes where too many homes are sharing broadband. A more likely explanation is a

configuration described as cascading. In the ideal network configuration Comcast would bring fiber to small nodes of a hundred or so homes. In a network with cascading, fiber is brought one neighborhood node, but then additional neighborhoods are added off this one fiber. The customers in the first node get the best download speeds, with subsequent nodes seeing slower speeds. We can't think of any other reason why homes would be getting download speeds under 50 Mbps and even 25 Mbps.

There are always some homes that get slow speeds due to having outdated WiFi routers – but we generally don't see this impacting more than 5% of customers in a market, so this can't explain the universally slow speeds in Falmouth.

Verizon DSL. The download speeds on Verizon DSL were mostly under 10 Mbps, which demonstrates that Verizon is still operating older versions of DSL technology in the town that were first installed in the early 2000s. Verizon no longer upgrades DSL technology, so these speeds will never improve. We expect within the next decade, and likely sooner, that Verizon will stop offering DSL (Page 40).

Fiber in Falmouth. Fiber broadband is provided by OpenCape to larger business, to government locations, and to the downtown business district, including a small number of residential customers. Comcast also is bringing fiber to some businesses. In total, only a tiny percentage of customers in Falmouth can buy broadband on fiber.

Upload Speed Gap. Much of the study was done after the start of the pandemic in March 2020. The pandemic uncovered a new broadband gap where residences began caring about upload speeds. Upload speed measures how fast data can be sent from a user's computer to the internet. Good upload speeds are needed for connecting to a school server, for working at home and connecting to a work server, and for connecting to online video meetings like Zoom. Additionally, just before the pandemic, many of the big gaming platforms moved their games online, creating a new demand for low-latency uploading. Many residents who thought they had adequate broadband suddenly found that they were unable to conduct multiple simultaneous upload connections at the same time. This phenomenon appeared all over the country as residences cared about upload broadband speeds for the first time.

The upload speeds in Falmouth are particularly sluggish. On Verizon DSL the upload speeds are all under 1 Mbps. On Comcast, 78% of upload speeds are under 15 Mbps, 55% are under 10 Mbps, and 14% are under 5 Mbps. Comcast reports to the Federal Communications Commission (FCC) that all of its customers in Falmouth can achieve upload speeds of 25 Mbps when only 15% are doing so. There is a discussion of upload bandwidth speeds starting on page 43.

The Broadband Gap is Growing. To add to the broadband gap problem, the demand for broadband is growing at an extraordinary rate. Perhaps the easiest way to understand this is through the average amount of bandwidth homes use each month. The following statistics are gathered and reported by OpenVault, a company that provides software for the large companies that operate the Internet backbone. In early 2018, the average home used 215 gigabytes per month of broadband (combined download and upload usage). By early 2019 this had grown to 274 gigabytes. By December 2019 the average home used 344 gigabytes. After the onset of the pandemic, by March 2020 the average home was using 403 gigabytes. This slowed a bit by June 2020, but the average home in the country was still using 380 gigabytes – a 74% increase since 2018 (Page 57).

According to Cisco, the amount of bandwidth used by homes has been growing at a steady rate of 21% annually since the early 1980s. Network engineers that operate broadband networks are terrified by the numbers cited in the preceding paragraph. Even if networks can handle the customer demand for bandwidth today, broadband networks will be severely distressed as broadband demand keeps growing at a torrid pace.

Other Broadband Gaps. The study examines other broadband gaps in Falmouth.

- The Affordability Gap. Like in all communities, there are residents of Falmouth that can't afford the cost of broadband. This was verified by the residential survey that showed that 9% of residents don't have a home broadband connection. This was further verified by discussions with the libraries that report that there are many residents of the community that rely on the broadband and computers available at the libraries. The libraries have recently been experimenting with lending WiFi hotspots to residents (Page 50).
- The Homework Gap. Falmouth, like other communities has students that don't have home computers or home broadband connections. The school system has addressed this issue during the pandemic by providing WiFi hotspots and Chromebook computers to students that needed help in order to connect to school classwork from home. These are temporary solutions and is something the community will have to continue to solve (Page 52).
- The Digital Literacy Gap. We had no easy way to measure this, but every community has residents who aren't comfortable working with computers or navigating the web. Communities are tackling this issue by ongoing basic computer training for residents (Page 56).

The Consequence of Slow Broadband Speeds. Slow broadband speeds put Falmouth at a competitive disadvantage. A recent national survey showed that one of the major consequences of the pandemic is that people are fleeing major metropolitan areas. As many as 23 million people plan to move in the coming year. Over 50% of the people who say they want to move are able to work from home and they are looking for communities that offer less costly housing and a better lifestyle than the cities they are fleeing. We talked to real estate agents in Falmouth who say there is a current real estate boom of people from New York City and Boston looking to relocate fulltime to Falmouth. One of the biggest hurdles the town faces is that the broadband is far better in these other markets than in Falmouth. Many urban customers in the Northeast are currently served by Verizon FiOS, which delivers symmetrical fast broadband on fiber. Comcast and other cable companies in the cities have upgraded networks to deliver the speeds they advertise. The broadband in Falmouth is not nearly as good as the broadband in nearby urban centers and the surrounding suburbs.

There is Market Demand for Better Broadband

As part of the study we looked at market demand. We first conducted a statistically valid random residential survey that asked about the current state of broadband with a target accuracy of 95% plus or minus 5%. The key findings of the survey are as follows: (Page 24)

- 91% of residents have a wired home broadband connection today, which is reasonably close to the national average.
- 88% said they are still buying a traditional cable TV package which is this is higher than the nationwide average, which was just under 70% at the time of the survey.
- One-third of respondents say they are unhappy with their current home broadband provider.
- Most residents in Falmouth are buying a bundle of multiple telecommunications services and the survey showed an average bundled monthly bill of $183 per month. That's one of the highest

numbers we've ever seen but is likely due to the large number of homes that still buy traditional cable TV.

- 53% of survey respondents said they are unhappy with the value they receive for the price they pay for telecommunication services.
- 70% of survey respondents support the idea of the town bringing a new fiber network, with an additional 16% saying they might support the idea but need more information. The primary reasons cited for wanting a fiber network are the hopes for more competition, the hope for lower prices, and the hope for more reliable broadband. .
- The key finding of the survey is that 36% said they would definitely buy from a new network; another 30% said they would probably buy service; 16% said they would consider buying service. Only 18% said they were unlikely to consider buying service from a new network. We interpret the survey to mean that as many as 61% of residents in Falmouth would consider moving broadband service to a new fiber network.

It's worth noting that the survey was done before the COVID-19 pandemic. Nationwide trends would suggest that the demand for broadband has increased during the pandemic as workers and students have been forced to function out of the home. The nationwide trends would also suggest that a lot of homes are starting to ditch the traditional cable TV products.

Business Questionnaires and Interviews. We communicated with businesses through a business questionnaire and through direct interviews. Here is what we learned from businesses: (Page 31)

- Every business that uses Verizon or Comcast told us their broadband speeds are "adequate," but that they would like faster speeds. The biggest complaint of the businesses that are not connected by fiber is the inconsistency of the broadband connection and the recurrence of outages.
- Almost every business told us that they didn't feel like they had any choice of Internet providers. Even businesses that use OpenCape fiber said they wanted a second competitive alternative.
- We reached out to businesses after the onset of the pandemic and heard that employees were having trouble working from home.
- We reached out to realtors that represent rental properties. They told us that 80% of potential renters now inquire about the availability of broadband. The number one complaint from seasonal renters is the inconsistency of the broadband connection – the same complaint we heard from residents.

Building a Fiber Network Would be Expensive

Our study considered wireless technology as well as several different fiber technologies. We found the most efficient and cost-effective new network would use Passive Optic Network (PON) technology using fiber to bring gigabit broadband to every home and business in the town. Our network design would also allow any large customers to be served using Active Ethernet technology that can deliver dedicated bandwidth speeds up to 100 gigabits per second (Page 69).

The fiber network is designed to go primarily on poles where other utilities are on poles but would be buried underground where other utilities are currently buried. The network design is robust and is designed to provide fiber for every home and business in the study areas today as well as the capacity for future expansion and growth. The extra capacity could be used for numerous reasons such as supporting electric smart-grid, supporting smart-city applications, or for providing for new housing and

business growth. Our engineers determined that a new fiber network would require 390 miles of new fiber construction on existing utility poles and 70 miles of new buried fiber construction

Following is a summary of the cost of building the network. This cost estimate considers a customer penetration rate of 50% at the end of year 5. The investment would vary with greater or fewer customers (Page 132).

Fiber	$41,260,625
Fiber Drops	$ 3,722,685
Electronics	$ 7,735,306
Operational Assets	$ 1,877,055
Total	$54,595,670
Cost per Passing	$ 2,272
Cost per Customer	$ 4,544

It's Financially Feasible to Build a Fiber Network

We considered a number of different potential business models. The report looks at the pros and the cons of the various operating models (Page 111). The study considers the following operating models:

- The town government or some other local entity like the EDIC would build and operate a fiber business.
- The town would attract a private ISP Internet Service Provider) to invest in building and operating a broadband business.
- The town would partner with an ISP to build an operate a broadband business. We discuss many variations on ways such partnerships might work.
- The town would build an open access fiber network and invite multiple ISPs to compete on the network.

Our Approach to the Financial Analysis**.** We created detailed financial models to quantify the potential for building and operating a successful ISP for each operating model. We used the following approach in estimating the revenues and costs for operating a new fiber network for each operating model (Page 125):

- A base model was created for each operating model. We arbitrarily chose a starting market penetration of 50% (the percentage of customers using the network). The residential survey had predicted a penetration rate of 61%, and we wanted the base study to be more conservative. We can't know how many customers a new fiber business might, but this penetration rate is typical for other similar fiber markets.
- All financial models cover a 20-year period.
- All projections include projected financing costs for borrowing the money needed to build and launch the network.
- We believe the engineering cost estimates are conservatively high.
- All studies include an estimate of future asset costs that are needed to connect future customers and to maintain and upgrade the network over time. We've assumed that electronics wear out and need to be replaced periodically during the studied time frame.

- Products were priced at a modest discount to Comcast rates since Comcast has the majority of existing broadband customers in town. The expectation is that the internet speeds on fiber will be significantly faster than the speeds available today.
- The estimates of operating expenses represent our best estimate of the actual cost of operating the fiber business and are not conservative. Most operating expenses are adjusted for inflation at 2.5% per year.

Key Financial Study Results**.** The assumptions used in creating the various financial plans for each scenario are included in Section III.C of the report. The results of the financial analysis are included in Section III.D of the report (Page 137). A summary of the financial results is included in Exhibit II (Page 210). Following are the key financial findings of our analysis.

It's Feasible to Operate a Fiber ISP in the Town. Most scenarios with a 50% market penetration are cash positive over 20 years, although there are scenarios where an ISP might struggle with that level of customers. Perhaps the key finding associated with profitability is the breakeven penetration rate. This represents the number of customers needed to create a business that should always remain cash positive. With revenue bond funding the breakeven penetration was calculated at a 48%. With bank financing the breakeven drops to a 42% penetration rate.

A Public-Private Partnership Could Succeed. There is enough potential profitability in the business models to contemplate public-private partnerships where the town builds a fiber network with an ISP partner.

Open Access Does Not Look Feasible. With open access the town would build a network and invite multiple ISPs to compete on the network. We could not find an open access scenario that is profitable for the town. This scenario does look to be profitable for ISPs that would operate on the network.

The Needed Debt to Financing is Significant. If the town financed the business with bonds the needed bond financing would be in the range of $70 million. Traditional commercial bank financing would require almost $8 million in equity and loans of approximately $55 million. Unfortunately, there are few private ISPs that would be able to raise the cash needed to build a fiber network in the town.

A Fiber Business is Sensitive to a Few Key Variables. All of the scenarios are sensitive to changes in a few key variables (Page 140):

- Penetration Rate: The most important variable is customer penetration rate. Our starting analysis was at a 50% penetration rate to be conservative. Our analysis shows that changing the penetration rate by just 1% will change cash over 20 years by $1.8 million. While that means a sizable boost in earnings for getting more customers than expected, it also uncovers the penalty associated with underperforming.
- Broadband Prices: The financial results are also highly sensitive to broadband prices. The studies all used an assumed starting price of $60 for the basic broadband product. Changing broadband prices higher or lower by $1 changes long-term cash flow over 20 years by $1.5 million.
- Rate Increases. The base models assume no rate increases to be conservative. It's possible in a competitive market that rate increases could be slim or even not happen. Raising rates by less

than 1% per year increases cash flow over 20 years by $8.9 million. Rate increases at some level will be needed to cover the cost of inflation.

- Interest Rate: The business plan scenarios are sensitive to changes in interest rates. A change of 50 basis points (changing interest rate from 3.5% to 4%) will change the cash flow in a bond-financed project by $6.1 million over 20 years. The impact on a bank-financed project is smaller, but still significant at $2.26 million over 20 years. While we've had a long period of over a decade where interest rates have remained steady, in a time of economic uncertainty it will be vital to keep an eye on interest rates.
- Loan Term. Increasing the length of loans by five years would provide a major benefit to financing fiber. With bond financing, changing from 25-year bonds to 30-year bonds would improve cash flow over 20 years by $10.9 million. With bank financing, changing from 20 years to 25 years improves cash flow by $10.4 million over 20 years.
- Changing Capital Costs. The impact of changing the amount of capital needed for a project has a much smaller impact than other variables. With bond financing, changing capital costs by $1 million changes cash flow over 20 years by $1.4 million. With bank financing the impact of changing capital costs by $1 million is a little less than $1 million.

Other Findings

There are other findings that are important for the community to consider when contemplating if you should try to build a new fiber network:

Existing Providers. The incumbent telephone company is Verizon, which provides broadband using DSL technology using copper. The incumbent cable company is Comcast. Some businesses and government entities in town get broadband from OpenCape, a local ISP that owns a fiber network that reaches across the town. There are residents who rely on cellphones for broadband. We looked at the key products and prices currently offered by the existing broadband providers (Page 15).

Passings. The telecom industry uses the term passing to mean any home or business that is near enough to a network to be considered as a potential customer. We used the town's robust GIS system to identify structures and potential customers. Our engineers settled on the following as the count of potential passings for the study.

Full Time Residences	14,232
Seasonal Residences	7,800
Business Passings	2,000
Total	24,032

Funding Options. The report discusses a wide array of funding options.

- Unfortunately, there are no grant programs we know of that could be used to build significant amounts of fiber in the town. The current federal and state broadband grant programs are aimed at rural markets. It's always possible to attract grant money for small incremental fiber builds like the grant used to serve the downtown business corridor.
- If the town finances the fiber network, all or most of the funding would likely have to come from municipal bonds.

- However, there are some interesting funding option worth considering such as direct tax funding, raising local start-up capital, partnering with an incumbent, and opportunity zone financing (Page 149).

Finding a Partner. The report describes the process of finding an ISP partner to help bring better broadband. The report doesn't suggest specific potential partners but describes the process used by other communities that have found and worked with ISP partners (Page 166).

Other Findings. The report also explores a number of other specific questions asked by the RFP.

- Future Technologies. The report explores if there are future technologies other than fiber that might present a competitive threat to any entity building a fiber network today, including 5G. We conclude that none of these technologies will be a strong competitor to a fiber network (Page 104).
- Summer Population. This report considers how better broadband fiber would impact the summer population in Falmouth (Page 61).
- Falmouth Community Television. The report explores the impact of a fiber network on Falmouth Community Television (Page 186).
- Fiber and Other Utilities. The report looks at how a fiber network might benefit the existing electric, water, and gas utilities (Page 191).
- Regional Fiber Solution? The report discusses the issues involved with collaborating with neighboring communities to create a larger and regional fiber business (Page 195).
- Other Cities that Have Built Fiber Networks. The report discusses some cities that have already built fiber networks like the one considered in the study. This includes cities that have been profitable, cities that have been unprofitable, and cities without electric utilities that have tackled fiber (Page 198).
- No Municipal Electric Utility. The RFP recognized that most cities that have built fiber already have an existing municipal electric utility. The report looks at what that means for Falmouth (Page 168).

Recommended Next Steps

1. **Decide if You Want to Proceed Further**. This study shows that it can be financially viable to build a fiber network and a fiber ISP in Falmouth. The study also demonstrates that there is enough likely customer demand in the community to support a fiber-based ISP.

   It's likely that this report will kick-off a more detailed discussion in Falmouth about the possibility of getting a fiber network. The decision to move forward with a fiber network is not an easy one. The three following recommendations address the need to figure out funding, local control of a new fiber business, and communicating with the public about a complex technical subject. Moving forward probably also means opening a dialogue with potential ISP partners if the town is not comfortable with the concept of operating a municipal broadband business.

   We think the first step after getting this report is to digest the findings of the report and then develop a specific plan and process for taking the next steps. Such a plan needs to be structured with time goals for reaching conclusions on the major elements of being able to make decision. Without a structured plan, the town could end up talking about fiber for years with no action.

2. **Educate the Public**. The report discusses a number of ways that other communities have educated the public on the broadband issue. The first step is to circulate this report. This written report was created for the purpose of explaining the wide range of issues associated with fiber to elected officials and the public. Our goal was to explain highly technical issues in plain English for the benefit of the nontechnical layperson.

   But there are many additional steps needed to bring the general public into the discussion of broadband. For example, many communities follow up a report like this one with neighborhood meetings intended to answer basic questions the public has about broadband. Most communities also begin the process of gathering public support and a method to further communicate with the public through such tools as a broadband website, a broadband newsletter, or some other kind of tool that can be circulated to discuss the progress of the investigation into fiber (Page 183).

3. **Figure out Funding.** Perhaps the hardest hurdle to overcome in getting a fiber network in any community is figuring out how to fund the network. That conversation can't be done in a vacuum and would include local government, the EDIC, and any potential ISP partner.

   We rarely see new community fiber networks funded from only one source. It wouldn't be surprising to see the funding for a network in Falmouth that derives funding from bond funding from the local government and/or the EDIC, from local equity or loans from community members, and from an ISP partner. There are also additional funding sources such as bringing in funding from a fund that utilizes Qualified Opportunity Zone funding.

   It's always complicated using funding from different sources because that requires figuring out such things as how each provider of funds is protected in the case the project doesn't succeed. This process of negotiating priorities of claims by lenders is one of the hardest challenges for this kind of funding.

But there is also the more mundane issue of getting funding commitments from different parties. Every party involved is going to hope that most of the funding comes from somebody else, and so there is always a process needed to take the money needed as identified from the business plan and turning that into specific commitments of exact amounts from the various funding sources.

4. **Figure out the Local Angle**. One message I heard from talking to various segments of the Falmouth community is that it is going to be important to have some level of local control and/or influence over any network and ISP that builds and operates a fiber network. This issue can probably best be described using the term governance, which asks about who decides policies for the new fiber business.

   Understanding governance is going to require two steps. First is to determine the structure of the new fiber business. There are numerous ways that the community could structure the business, and these are discussed in the report. This would include options like creating a municipal utility, creating a broadband cooperative owned by customers of the business, creating a non-profit business to operate the network, or creating a for-profit corporation. There are pros and cons for each of these business structures. The business structure can't be decided in a vacuum and the decision on how to fund the business might eliminate some of these options (Page 118).

   The second step is then deciding within the chosen business structure how to define governance. Generally, anybody that provides a large share of funding is going to want to have some say into how the business is operated. Some lenders might have strong opinions on the topic that must be followed in order to get the funding. There is also going to be interest in somehow including the local government, the EDIC, or other local voices into the governance structure. Finally, any operating ISP is going to have a strong opinion – commercial ISPs are almost automatically leery of local control by government.

   Governance can get complicated and will eventually include specific details about how various parties vote on issues, and what happens when a consensus can't be reached. But that is the last step in the process. The specific recommendation is that the community tackle the governance issues such as business structure as part of considering moving forward.

5. **Talk to Potential ISP Partners**. This report provides a list of steps that other communities have undertaken in finding and opening a dialogue with potential ISP partners. The process most favored by ISPs in an informal process where discussions can be had that are not in writing or on the public record. Some communities insist on a more formal process, and that can drive away some potential ISP partners.

   The early stages of talking to ISPs are first to find out the level of interest in providing the local ISP function in Falmouth. There are numerous other aspects of working with an ISP that can't be fully explored until the decision has been made about important steps like the business structure and the way the business will be governed. ISPs are obviously going to be highly interested in understanding how they will be compensated for their effort.

There are numerous parameters for judging ISPs and each community must decide your specific priorities. For example, if there is an expectation that an ISP brings some funding, then that eliminates ISPs that can't bring funding.

While any discussions held with ISPs are preliminary, we think it's a step worth taking early in the process, because the ISP partner chosen is likely to influence some of the other questions such as business structure, governance, and funding (Page 166).

6. **Find a Local Champion**. It's been CCG's experience that a project of this magnitude is not going to progress unless there is some kind of local champion. A local champion is some person or group that is tasked with tackling the various recommendations made in this report. A local champion clearly has to be pro-broadband, but open to all possibilities of how this might work in the community.

   Communities have staffed the ongoing effort in a number of ways. There are communities for which broadband is such an important issue that the dedicate government or economic development staff to the issue. It would be unusual for this to effort to immediately be a full-tie task, but eventually it could become so.

   But typically, government staffing is not going to be efficient to move the broadband issue forward. That's not hard to understand by looking at these recommendations and seeing a list of issues must be tackled like public education and outreach, funding, governance, finding an ISP partner, etc.

   Most communities that have successfully tackled getting broadband network also bring in volunteers from the community. Falmouth already has a volunteer broadband committee, but the ongoing volunteer effort is likely to be different than that. To be effective, volunteers need to be organized and giving specific tasks to achieve and a schedule to meet. It would be somewhat normal to have several different volunteer committees that tackle different issues. Such volunteer efforts need some level of funding to achieve their goals. It's also important that any volunteer efforts have oversight to make sure they are headed in the right direction.

   The recommendation is to identify and activate both government and volunteer resources and to develop a plan to use these staffing resources to tackle the various issues associated with broadband. The most successful efforts require that staffing be directed to solve specific tasks, given specific timelines to meet, and are properly funded to achieve the goals.

7. **Tackle the Steps that Can Reduce Construction Costs**. The study identified a few steps that can be taken that could reduce the cost of the network that has been estimated by CCG engineers. One issue is the cost of make-ready, which is getting poles in the town ready to accept fiber. One of the issues we've identified is that there are many residential streets where trees are going to need to be trimmed before fiber construction can take place. This is normally the responsibility and at the cost of the existing companies that have wires on the poles. The community needs to take steps to see that tree trimming is up to date before tackling fiber construction.

   We also think there are possibilities for sharing fiber with OpenCape. In many cases a second fiber is going to have to be built along the same routes where OpenCape already has fiber. But

there may some neighborhoods where OpenCape already has enough fiber to serve all of the local potential customers. There are likely some existing OpenCape fiber routes where leasing a few fibers from OpenCape might be all that is needed to avoid new construction, particularly on some of the roads that reach between the neighborhoods in town. Finally, there might be a savings if there are places where a new fiber could share the same space on the pole as the OpenCape fiber.

Determining these savings will likely require more detailed engineering, and the specific details of these savings might require a block-by-block determination.

8. **Reach out to Verizon**. Verizon has begun to deploy a fixed wireless technology being marketed as FWA (Fixed Wireless Access). The product is described in more detail in Section II.C. of the report. This technology involves building fiber on residential streets and then beaming broadband into the home using millimeter wave spectrum. In terms of technology we call this fiber-to-the-curb. Verizon currently claims to be achieving speeds close to a gigabit with the new technology, which is currently being introduced in neighborhoods in Detroit and a few other cities. Verizon says they plan to deploy the new technology to pass 30 million homes, so they company will be making significant investments in fiber in neighborhoods.

   Verizon never brought its fiber FiOS product to the Cape and we have no idea if the company is thinking about bringing this technology to Falmouth or other towns on the Cape. The town should reach out to Verizon to see if they will share their intentions.

   There are a few things we understand about Verizon that need to be considered with this technology. The company is unlikely to bring the technology to all of Falmouth even if they are coming to Falmouth. Verizon is a highly disciplined overbuilder in that they only build where costs meet certain parameters. When Verizon built FiOS fiber, it didn't build to the "best" neighborhoods, but rather to neighborhoods where the construction costs fell within the company's cost goals.

   It's not an easy decision to invite Verizon and the technology to town since they will only bring it to some parts of the town. That would result in a town where some neighborhoods have choice while other would be stuck with only the Comcast monopoly. If Verizon is coming to town it might be possible to partner with them to complete the build somehow. We're not aware of Verizon ever entering in this kind of partnership, but we're seeing other large telcos like CenturyLink and Consolidated partnering with communities to bring gigabit broadband.

9. **Be Persistent.** The path to go from this report has a lot of moving parts and is likely to move forward by fits and starts. We caution the town to be persistent if you really want fiber – if not, you might bet stopped by roadblocks that pop up along the path to get fiber.

I. MARKET ANALYSIS

A. Providers, Products and Price Research

The two major incumbent residential service providers are Comcast and Verizon. According to the survey, Comcast has won the majority of customers in town. Both incumbents also serve the business market. OpenCape has built fiber to the larger businesses and anchor institutions in the town. There are also residents in the town who use their cellular phones as the only source of home broadband.

Incumbent Telephone Company

Verizon. Verizon is the incumbent telephone company in Falmouth. Verizon was formed under the name of Bell Atlantic as a spin-off from AT&T in 1984. Verizon is the second largest cellular company in the country after AT&T. As of the end of the first quarter of 2020 Verizon was the fourth largest ISP in the U.S. with just under 7 million broadband customers along with 4.1 million video customers. Verizon purchased AOL in 2015 and in 2017 purchased Yahoo. In recent years, the company sold a significant number of customers to Frontier Communications, mostly properties outside of the northeast corridor.

Stand-Alone Internet

Verizon delivers broadband using two technologies. In cities where it's built fiber, the company sells under the FiOS brand name. FiOS currently offers three Internet products with speeds of 200 Mbps, 400 Mbps or 940 Mbps. FiOS is not available in Falmouth.

In Falmouth, the company still offers broadband using telephone copper wires using DSL technology. The company pushes customers to buy a bundle of telephone and Internet, but it will sell standalone DSL.

Verizon only has one DSL product in Falmouth that offers speeds up to 15 Mbps. The list price for standalone DSL is $49.99 per month. As this report was being written the company was offering a web special for $40 per month that would be good for a year.

Verizon has been aggressive with price increases on DSL. There are customers that were paying less than $20 per month a decade ago that have been increased over time to the current $49.99 price.

Verizon allows customers to provide their own DSL modem and WiFi router. Verizon is currently selling a combined DSL/WiFi box for $50, and these are also available from electronics vendors. Customers report a range of different rental fees if a customer chooses to lease the box from Verizon, with the most commonly cities prices being $5 and $7 per month.

Telephone Service.

Verizon currently is only offering Verizon Freedom Essentials to new customers on the web. This is a telephone line that includes unlimited long distance and up to five common features. Verizon is currently advertising this as an add-on to a DSL connection for $25. But there are customers who have gotten the product in a bundle for as little as $15 – the amount charged for bundling varies according to how and when a customer subscribed. There are grandfathered customers who are buying other Verizon telephone products with DSL.

Verizon also provides some customers an additional bundling discount for those that are using the company for cellular service.

Customer Support. Verizon supports technical questions about broadband for a limited time after installation. Customers that want a guarantee to task to tech support are asked to subscribe to Tech Support Pro at a cost of $10 per month.

Verizon also offers a premium support product called Verizon Protect Home. This product costs $25 per month. It provides 24/7 access to tech support. It also covers two in-house visits by technicians per year. Verizon will replace any non-working Verizon devices for free for subscribers of the plan. The product also comes with a suite of security and WiFi protection software.

Incumbent Cable Company

Comcast Xfinity. Comcast is the incumbent cable TV provider in Falmouth. Comcast markets and bills using the "Xfinity" brand name. The company offers the traditional triple play of cable TV, internet, and voice services. Comcast is the largest cable TV company in the US with 2019 revenues of nearly $109 billion, and the second largest cable company in the world. They are headquartered in Philadelphia. At the end of the first quarter of 2020 the company had 29.1 million broadband customers and 20.8 million cable customers.

In addition to providing triple-play services the company owns a number of media assets like NBC, Telemundo, MSNBC, CNBC, USA Network, The Golf Channel, Syfy, numerous regional sports networks, Universal Pictures (and theme parks), DreamWorks, and the Philadelphia Flyers hockey team and arena. The company now sells cellular phone service. They are also probably the largest seller of smart home services in the country.

Stand-Alone Internet[1]

Comcast offers significant discounts to some new customers. Promotional products eventually revert back to list price, generally within one or two years. Following are the most recent list prices for standalone Internet.

Performance Starter	15/2 Mbps	$ 53.00

[1] The Comcast rate sheet as of December 2019 is at: https://comcaststore.s3.amazonaws.com/prod/wk/urc/585bc4be5bcd10375b2cf1d8/high_res/UC0000002_sik_high_res.pdf

Performance Plus	60/5 Mbps	$ 73.00
Blast! Pro	150/5 Mbps	$ 83.00
Extreme	250/10 Mbps	$ 93.00
Gigabit	1,000/35 Mbps	$113.00
Gigabit Pro	2,000/2,000 Mbps	$299.95
WiFi Modem (for all products)		$ 14.00

We don't believe that new customers can buy the 15/2 Performance Starter product, so the minimal Comcast product is now priced at $73 after the end of any promotional discounts.

Comcast raised broadband rates by $3 and the cost of the modem by $1 in December 2019. Industry analysts expect prices to increase annually.

Comcast has data caps. Most broadband products are capped at 1 terabyte of download per month (1,000 gigabytes). There are lower caps that apply to grandfathered legacy products. When customers exceed that cap for a given month (the usage adds together both download and upload data usage), Comcast bills $10 for each additional 50 gigabytes of data used, with a maximum of $50 extra.

Telephone

Comcast sells standalone residential telephone service. The prices are as follows.

Basic	$30.00
Additional Line	$ 9.95

The basic line is a telephone line with the standard features but no long-distance option. Comcast used to offer a telephone line with unlimited long distance, but that's no longer in their price list. My guess is that they will direct customers to the Comcast cellular service for those wanting unlimited calling.

Cable TV

The following prices are for standalone cable TV. These packages follow the tiers of service required by the FCC. The Limited Basic tier includes the network broadcast channels like ABC, CBS, FOX, NBC and PBS. The tier also has a number of other channels such as shopping channels and a few others – varies by market. The Extra tier includes most of the popular channels that people expect from a cable subscription. Finally, the Preferred tier adds on a number of additional channels and includes every non-premium channel offered by Comcast.

Limited Basic	$32.95
Extra	$70.00
Preferred	$90.00
Set-top box	$10.45
DVR Service	$10.00

Comcast adds the following fees to every cable subscriber.

Broadcast TV Fee	$14.95
Regional Sports Fee	$ 8.25

These fees are controversial. There is currently a lawsuit filed by the State of Minnesota that is challenging these fees. Lori Swanson, the Attorney General of Minnesota sued Comcast in 2018 seeking refunds to all customers who were harmed by the company's alleged violation of the state's Prevention of Consumer Fraud Act and Uniform Deceptive Trade Practices Act.

These two fees are a part of every cable package and are not optional to customers. Comcast doesn't mention the fees when advertising the cable products. Further, Comcast customer service has repeatedly told the public that the fees are mandated by the government and are a tax that is not set by Comcast.

Comcast only started charging separately for these two fees in 2014, but the size of the fees has skyrocketed. In recent years the company has put a lot of the annual rate increases into these fees, allowing the company to continue to advertise low prices. The Regional Sports fee passes along the cost of regional sports networks. The Broadcast TV fee includes the amounts that Comcast pays local affiliate stations for ABC, CBS, FOX, and NBC.

Comcast argues that breaking out these fees makes it easier for customers to know what they are paying for – but there are numerous examples cited in customer complaints where new customers were surprised at the size of the first bill they receive from the company.

The Comcast Bundle

It is important for anybody that wants to compete against Comcast to understand the power of its bundles. The most obvious reason for giving bundles is to entice customers to buy more than one service from the company, and Comcast provides increasing discounts for customers that buy multiple products. Because the company has so many products, it offers a dizzying array of bundles, with prices that change often as inducements to get customers to buy additional products. Comcast has learned that customers that buy multiple products - particularly products in addition to the triple play – rarely churn and become loyal customers.

One of the most important aspects of the bundles are that they punish customers for dropping a bundled service. Consider the following simplified example of how this works. Suppose that a customer purchased the $73 broadband product and the $70 cable product and is given a $20 bundling discount and charged is $123 for the bundle. If a customer drops either product, the customer loses the entire $20 discount and remaining product reverts list price.

Customers never know what they pay for any given product within the bundle. For example, there are bundles that make it look like a customer is getting telephone service for free. But if the customer breaks the bundle and wants to keep only telephone with Comcast it reverts to the prices above.

This is one of the primary reasons that most competitors to Comcast offer cable TV. Otherwise, if a customer tries to change just their broadband to the new provider but leaves cable TV with

Comcast, they are charged a "penalty" for breaking the bundle. Once customers understand the financial consequences of breaking the bundle, many won't change to a competitor since they might not get any net savings.

Comcast has expanded the bundle in the last few years. Their newest offering is cellular service which is only available for customers buying Comcast broadband. The pricing is simple, and inexpensive. Customers pay by the amount of data used, at $12 per gigabyte. A customer using less than 1 GB of data pays only $12 per month for the connection. For $45 per month customers get unlimited data. Comcast uses the Verizon network to carry the traffic, but the company recently purchased spectrum and is planning on providing the service directly to customers in some markets.

Comcast also provides smart home products under the brand name of Xfinity Home. The company is now supporting the home automation devices of nine major manufacturers: August (smart locks), Automatic (automobile), Cuff (fitness tracking), Lutron (smart lighting), Leeo (alarms), Nest (thermostat), Rachio (sprinkler system), Skybell (doorbell), and Whistle (pet tracking). It's an impressive suite of products and is all integrated through the Comcast portal.

Comcast also offers traditional home security with hardware developed at Comcast Labs. This includes the traditional suite of burglar, fire, and other alarms that are monitored and reported to authorities when there is a problem.

Other Incumbent Provider

OpenCape Corporation is a 501(c)(3) non-profit corporation that owns an extensive fiber network throughout Cape Code and southeastern Massachusetts including connectivity back to Boston. The company is headquartered in Barnstable Village.

OpenCape acts as an Internet Service Provider (ISP) for more than one hundred institutions including libraries, government buildings, schools, colleges, hospitals, public safety agencies and research institutions. They also serve large business customers. The company operates an active Ethernet network that can provide speeds as fast as 100 Gbps.

In Falmouth, OpenCape provides connectivity between nineteen buildings operated by the town. OpenCape provides connectivity to provide the survivability of public safety networks during bad weather conditions. OpenCape also connects to the schools in Falmouth as well as places like the business park, research facilities, and other key employers in the community.

Main Street Initiative. In 2019, The Falmouth EDIC and OpenCape received state funding to provide fiber connectivity to businesses located along Main Street in Falmouth, as well as businesses in Woods Hole. Merchants reported significant problems with existing broadband such as being unable to process credit cards and in having periodic network outages during the tourist season.

The project will bring a shared gigabit of bandwidth to the business districts. Merchants have three options for connecting. They can pay the $400- $600 connection charge up front, with the options to spread the connection fee over a year. Businesses and non-profits that qualify can get the installation fee covered by a grant through the joint EDIC / Open Cape program. Open Cape is selling a gigabit

broadband connection to downtown businesses for a rate of $117, guaranteed for 2 years and is also offering broadband to residents who live in the immediate neighborhood of the fiber.

Other Providers

Dish Network is a large satellite provider and has customers in the county. The company had around 9.5 million cable customers nationwide at the end of the third quarter of 2019. Dish Network now also offers an Internet-based cable product branded as Sling TV. This service offers an abbreviated channel line-up and costs less than traditional cable products.

Dish Network has the same pricing nationwide. The standalone price with no discounts is as follows:

190 Channels	$ 79.95
190 Channels +	$ 84.99
240 Channels +	$ 94.99
290 Channels +	$104.99

It's worth noting that Dish now plans to become the fourth major cellular carrier in the country. This expansion was activated from negotiations involved in the merger between T-Mobile and Sprint.

DirecTV is one of the largest cable providers in the US. The company is now owned by AT&T. The company had 16.8 million cable customers at the end of 2019, down almost 2.4 million customers during 2019. AT&T has decided to end all discount packages, resulting in significant rate increases for many customers who were getting various promotional discounts. DirecTV now offers an online version of its programming that was called DirecTV Now, but which was recently renamed as AT&T TV.

Current prices after any promotional discounts are:

155 Channels - Select	$ 85.00
160 Channels - Entertainment	$ 97.00
185 Channels - Choice	$115.00
235 Channels – Xtra	$131.00
250 Channels - Ultimate	$142.00
330 Channels - Premier	$197.00

The above includes rate increases effective January 2020 that range from $4 to $8 per month.

Satellite Broadband.

There are two satellite broadband providers available to homes and businesses. Both Viasat and HughesNet utilize satellites that are parked at a stationary orbit over 20,000 miles above the earth.

There are a few problems that customers consistently report with satellite broadband. Customers complain that satellite costs too much (Viasat claimed in their most recent financial report for June 2019 that the average residential broadband bill is $84.26). Customers also hate the high latency, which can

be 10 to 15 times higher than terrestrial broadband. The latency is due to the time required for the signals to go to and from the satellites parked at over 22,000 miles above earth – that adds time to every round trip connection to the web. Most real-time web connections, such as using voice-over-IP, or connecting to a school or corporate WAN prefer latency of less than 100 ms (milliseconds). Satellite broadband has reported latency between 400 ms and 900 ms.

The other customer complaint is about the tiny data caps. As can be seen by the pricing below, monthly data caps range from 10 gigabytes to 150 gigabytes. To put those data caps into perspective, OpenVault announced recently that the average US home used 344 gigabytes of data per month in the fourth quarter of 2019, up from 275 gigabytes in 2018 and 218 gigabytes in 2017. They also reported that the average cord-cutting home used 520 gigabytes per month in 2019. The small data caps on satellite broadband make it impractical to use for a household with school students or for a household that wants to use broadband to work from home.

Viasat (was formerly marketed as Exede or WildBlue) offers broadband from one older and also a newer satellite. Following are the products from Viasat:

	Price	Speed	Data Cap
Liberty 12	$30	12 Mbps	12 GB
Liberty 25	$50	12 Mbps	25 GB
Liberty 50	$75	12 Mbps	75 GB
Unlimited Bronze 12	$50	12 Mbps	35 GB
Unlimited Silver 12	$100	12 Mbps	45 GB
Unlimited Gold 12	$150	12 Mbps	60 GB
Unlimited Silver 25	$70	25 Mbps	60 GB
Unlimited Gold 50	$100	50 Mbps	100 GB
Unlimited Platinum 100	$150	100 Mbps	150 GB

Online reviews say that speeds can be throttled as slow as 1 Mbps once a customer reaches the monthly data cap.

HughesNet is the oldest satellite provider. They have recently upgraded their satellites and now offer speeds advertised as 25 Mbps download and 3 Mbps upload for all customers. Prices vary according to the size of the monthly data cap. Their packages are as follows:

10 GB Plan	$ 59.99
20 GB Plan	$ 69.99
30 GB Plan	$ 99.99
50 GB Plan	$149.99

These packages are severely throttled after meeting the data caps.

Cellular Data

There are four primary cellular companies in the country—AT&T, Verizon, T-Mobile, and Sprint. As this paper was being written, the courts approved the final challenge to a merger between T-Mobile and Sprint. Part of the merger conditions was that Sprint would provide spectrum that would allow Dish

Networks to become the fourth cellular nationwide carrier.

The residential surveys showed that 5% of households use their cellphone data plans for household broadband. There are a few issues that are experienced with cellular data. First, customer speeds decrease with distance from a cellphone tower, so cellular data speeds are not the same everywhere in town. Data speeds also weaken when passing through walls into building, so indoor speeds are not as fast as outdoor speeds.

Following are the nationwide average 4G data speeds for the four carriers, shown for 2017 and 2019. Speeds are improving over time. However, these are nationwide averages and rural customers likely get slower speeds than these averages.

	2017	2019
AT&T	12.9 Mbps	17.8 Mbps
Sprint	9.8 Mbps	13.9 Mbps
T-Mobile	17.5 Mbps	21.1 Mbps
Verizon	14.9 Mbps	20.9 Mbps

All four carriers now offer "unlimited" data plans. The plans for AT&T, Sprint, and Verizon are not actually unlimited and have monthly data caps in the range of 20 - 25 gigabytes per month of downloaded data. These plans might provide some relief to homes that rely on cellular broadband, although there have been reports of Verizon disconnecting rural customers who use too much data on these plans. These plans allow have limits on how much data can be used when tethering from a cell phone for use in other devices, so the plans are not much more useful for home broadband than normal cellular plans. T-Mobile claims to offer unlimited data but begins throttling customers after 50 GB of data usage in a month.

There are two different cellular data standards in use: 3G and 4G. 3G data speeds are capped by the technology at 3.1 Mbps download and 0.5 Mbps upload. There are likely to still be some 3G cellular towers in rural parts of the county. The amount of usage on 3G networks is still significant. GSMA reported that at the end of 2018 that as many as 17% of all US cellular customers still made 3G connections, which accounted for as much as 19% of all cellular connections. Opensignal measures actual speed performance for millions of cellular connections and reported the following statistics for the average 3G and 4G download speeds as of July 2019:

	4G 2019	3G 2019
AT&T	22.5 Mbps	3.3 Mbps
Sprint	19.2 Mbps	1.3 Mbps
T-Mobile	23.6 Mbps	4.2 Mbps
Verizon	22.9 Mbps	0.9 Mbps

B. Residential Survey

The first phase of the Broadband Feasibility Study was to conduct a residential survey to understand residential interest and demand for a new fiber network in the town.

Survey Methodology

The survey covers the town boundary of Falmouth.

The survey was conducted by telephone. The Falmouth EDIC wanted this survey to represent households across the socioeconomic and age range, and the easiest way to get that broader mix is to include cell phones in the survey. Some of the largest survey companies that undertake nationwide surveys have reported that households with landlines tend to be older and more conservative than the average household in a community. It's become obvious that giving surveys only to landline households will skew the results.

The town provided CCG with a list of telephone numbers that it gathered from voter registration records that included both landline and cellular telephone numbers. One of the interesting aspects of using telephone numbers from voting records is that everybody on the list considers themselves to be a resident of Falmouth, other than perhaps folks who have moved since the Town gathered their phone numbers.

A survey must be conducted randomly, meaning that the calling shouldn't be clustered around any one particular portion of the study universe. For example, the survey would not be considered to be valid if all of the calls were placed only to one portion of the town.

Since Falmouth is a community with distinctly different neighborhoods, we thought it was important to try our best to reach all parts of the community. The telephone records we obtained were sortable by voting precinct, so we purposefully collected a set number of surveys from each voting precinct to give us the desired geographic diversity. When doing surveys, this method is called directed calling, and the method is still a valid sampling technique as long as we were completely random in choosing numbers inside each voting precinct. Our method of using the list of numbers for each precinct was to call every tenth phone number on the list after each completed call. We cycled through the calling list for each precinct until we got the desired number of completed surveys.

Most business and political surveys strive to achieve an accuracy of about 95% with results that are plus or minus 5%. In layman's terms, this means that the results of such a survey are reliably accurate (the 95% number) and you would expect to get the same results (within 5%) if you could ask the same questions to everybody in the Town.

CCG uses an online survey tool to determine the number of surveys needed to achieve the desired accuracy. The tool is provided by Creative Research Systems and is found online at https://www.surveysystem.com/sscalc.htm. We've used this tool for many years and have manually done the mathematical calculations that demonstrate that the tool is accurate. This tool told us that we needed 378 completed surveys in Falmouth to achieve the desired accuracy of 95%, plus or minus 5%.

In the US we know that many people distrust the results of surveys, mostly due to results obtained for political surveys. This speaks to the issue of bias. When callers are asked about sensitive topics like politics, religion or anything personal or controversial it's well-known that many respondents don't answer questions honestly to a stranger like a survey taker. The best example of this is when surveyors ask people for their household income. Survey companies have often said that as many as half of residential homeowners will not give an accurate response to the salary question.

However, experience shows that there is high reliability with surveys that look at non-emotional topics, such as this survey talking about a routine product purchased by most households. We have anecdotal evidence that they broadband surveys are good market predictors because CCG has been giving these surveys for 20 years and we've had many opportunities to see the broadband penetration rates in communities to compare to the predictions made by our surveys. Surveys are never 100% accurate because sometimes an ISP does something to change the public perception. For example, an ISP that has problems during a network launch might underperform a survey. In general, we've learned to have faith in the predictions made by these broadband surveys.

Survey Results

The survey produced some interesting results. A full copy of the survey questions and the responses are included in Exhibit I of this report. Here are highlights of the survey results:

The Survey Respondents

Since the telephone numbers we used came from voter rolls, it was expected that most people we called would be residents. That held true to expectations and 95% of respondents were fulltime residents of Falmouth. 2% of respondents live in Falmouth and rent their homes to others full time. 3% of respondents rent their homes for part of the year, between 6 and 9 months.

Broadband Customers

91% of survey respondents have some form of landline broadband. 83% of respondents use Comcast and 8% use Verizon. We normally see a larger percentage of homes still using the incumbent telco, so it's apparent that Comcast has done better than normal in capturing the Falmouth market. Nationwide the big cable companies have twice as many broadband customers as the big telephone companies.[2] The survey didn't ask about this difference, so we don't know why such a large percentage of residents use Comcast. We can speculate that the DSL network in the town might be in bad condition – but that is purely speculation and there might be other reasons why Comcast has done so well.

CCG Consulting has been tracking the nationwide telecom markets for years and we know that customers nationwide are abandoning telco DSL in favor of the faster cable modem broadband. In 2018 we saw the big cable companies collectively gain over 2.9 million new customers for the year while the largest telcos collectively lost almost half a million customers.

The FCC reports that almost 86% of homes nationwide now have a broadband connection. However, the FCC nationwide numbers are skewed because the numbers don't account for the roughly 14 million rural homes in the country that have no option to buy broadband. If the FCC statistics are adjusted for those homes, then the nationwide average broadband penetration everywhere except those rural areas is 93% - right in line with the results of this survey. (This is a good reason to always be careful when using a nationwide statistic – unless you know how it's calculated.)

The mix of customers between Comcast and Verizon is not the same everywhere. For some reason all of the Verizon customers we surveyed live in voting precincts 3, 4, and 6.

[2] At the end of the first quarter of 2019 the big cable companies had 64.3 million broadband customers while the big telcos had 33.4 million customers.

Another 4% of the respondents said their only source of broadband is cellular. Nobody claimed to be using satellite broadband. Only 5% of the respondents have no broadband access.

Cable TV Penetration

In another interesting result, 88% of survey respondents report the purchase of traditional cable TV. That is significantly higher than the nationwide average, which dipped below 70% early in 2019. In Falmouth 79% use Comcast, 5% use Verizon, and 4% use satellite.

One of the puzzling aspects of the results is the Verizon cable TV product. To the best of our knowledge, Verizon only offers cable TV over fiber. We've been told that the town has good knowledge that Verizon doesn't provide their fiber-based FiOS products anywhere on the Cape – the most typical way that Verizon provides cable TV. Verizon does sometimes sell broadband and other products on fiber to apartments, condominiums, townhouses, and similar properties and it's possible that there are a few places in the community with this kind of wholesale fiber connection.

We also note that the number of households using satellite TV is smaller than what we normally see. In most towns, the satellite penetration of cable TV is often between 10% and 15% of homes. The survey didn't ask customers why they chose their current provider, so we don't know why there are a smaller than expected number of homes using satellite TV.

Only 4.5% of survey respondents claim to be cord-cutters that watch all content online. There are not yet any reliable count of the market share of cord-cutters, but most estimates put it somewhere between 15% and 20% of households. The percentage of cord-cutters is growing rapidly, so it is expected for the homes with traditional cable in the town to drop over time.

Telephone Penetration

60% of homes still claim to have a landline telephone. The nationwide landline penetration has dropped below 40%.

This is the one statistic from the survey that we can't fully trust. This statistic could be driven by the percentage of landlines that are included in the list of telephone numbers. We have no way of understanding the mix of cellular and landline telephone numbers in the numbers provided to us since numbers can be transferred to and from landlines and cellphones today. It's also possible that this is an accurate statistic and that the town has a significant percentage that still uses landlines.

Customer Bills

The survey asked customers what they pay each month for the triple-play services (Internet access, cable TV, and telephone). We've found that this question always has to be taken with a grain of salt because what people say they pay is often quite different than what they actually pay. For example, a household

might cite a $100 special price they are paying without realizing that they actually pay more due to hidden fees and additives. It's especially easy these days for customers that pay automatically with credit cards or bank debits and not know how much they pay.

With that said, here is what customers say they are spending:

Customers buying a bundle of service	$183
Customers buying standalone broadband	$ 92
Customers buying standalone cable TV	$ 59
Customers buying standalone telephone	$ 72

We note that the $183 average for bundles is one of the highest amounts we've ever seen on a survey. Most communities average less than $150. One of the factors that might be driving this high number is the small percentage of homes that claim to be cord-cutters. Cable TV is the most expensive portion of the Comcast bundle, so having a higher percentage of cable users would drive up this average price.

Uses of Broadband

26.5% of respondents say that somebody in their homes uses the Internet to work from home. That is made up of those that work at home fulltime (4.5%), those that work several days per week (8.5%), and those that work from home occasionally (13.5%).

22% of respondents report having school-age children at home.

Satisfaction with Existing Broadband

27% of respondents say they are unhappy with their Internet download speeds at home, while 33% are satisfied.

33% of respondents are not happy with the customer service from their ISP, while 31% are satisfied with customer service.

36% of homes are not satisfied with the reliability of their broadband connection, while 28% are satisfied.

53% of respondents say that they are unhappy with the value they get from their ISP compared to the price they pay. 26% of homes are satisfied with the value they are getting.

We asked about Internet outages in the last year. 51% of respondents said they have had an outage (where there is no Internet access). 15% of those with outages only experienced outages for a short time. 45% reported outages of one day, and 45% said that had had an outage that lasted multiple days. 53% said the outages were very inconvenient and only 2% weren't bothered by the outages.

We also asked about Internet slowdowns, where the broadband speeds sometimes are slower than normal. 63% of respondents said they had noticed Internet slowdowns in the last year. Just over half said the slowdowns seemed to happen at random while the rest said that they noticed them daily. 64% of

respondents said they found the slowdowns to be annoying or bothersome. Only 1% of respondents weren't bothered by the slowdowns.

Support for a Fiber Network

One of the key questions asked in the survey is if respondents support the idea of Falmouth trying to get better Internet access. 70% of households support the concept. Another 16% said they might support the idea but need more information. Only 14% of households said they do not support Falmouth pursuing a better broadband solution.

We asked the reasons why respondents support bringing a new network to the town. An overwhelming 92% said they hope for more competition. 79% of households hope for lower prices. 55% of respondents hope for more reliable service. 41% of respondents hope a new broadband solution would mean better customer service.

We then asked all respondents which factors would lead a household to move their service to a new network. 82% said that lower prices would make them consider changing. 59% of respondents would be interested in better network reliability. A smaller 45% liked the idea of having faster Internet speeds for the same price they pay today. 24% said they might change to keep profits in the community. Only 20% of respondents thought that better customer service from a new network provider would be a lure.

We asked the reasoning for respondents who don't support a new fiber network - recall from above that this is 14% of all respondents. 81% of these respondents are happy with their current provider and see no reason to switch. 17% of respondents don't use broadband.

Switching Service to a New Network

In probably the most important question of the survey, we asked households if they would buy Internet service from a new fiber network. 36% said they would definitely buy. Another 30% said they would probably buy service and 16% said they would consider buying service. Only 18% said they were unlikely to consider buying service.

We next asked if respondents would buy cable TV from a new network. 32% said definitely yes and another 29% said probably. Only 20% said they were unlikely to buy cable TV.

When asked if they would buy a landline telephone, only 14% of the respondents said yes with another 19% saying probably. 48% said they were unlikely to buy a landline.

Questions for Landlords

We had a few questions aimed at landlords that rent their property to others, either part-time or for the whole year. Only 3% of respondents say that they rent their home to others. There was hope that the survey would reach more people in this category. I guess that since the calling numbers come from the voting rolls that the universe of callers is heavily weighted towards those that consider themselves as Falmouth residents, which seems to be mostly full-time residents.

Since the universe of respondents is so small for these question it is not possible to put any statistical importance on the response – meaning that the way that this handful of respondents answered might not represent the larger universe of homeowners that rent their property for parts of the year.

With that said, those that rent their homes say that they can get seasonal billing from their ISP (meaning Comcast). Seasonal billing means that homeowners don't pay full prices during periods when the home stands empty. Every homeowner who rents said it is important or very important for the rental units to have good broadband. One-third of respondents said they've received complaints from renters about the broadband.

Interpreting the Results of the Survey

It's always a challenge to interpret survey results. It's easy to interpret a broadband survey in a rural community that has poor broadband, and we have done surveys where 80% to 90% of citizens support a new fiber network. It's much more of a challenge to understand what the responses are telling us in a town like Falmouth. Proponents of fiber will see plenty of support in the survey responses, but opponents of fiber can probably say the same thing. Following are my observations of what your survey tells us:

Dissatisfaction with the Incumbents. The surveys show that generally, residents aren't as unhappy with Comcast as the town might have imagined. 27% of respondents were unhappy to some extent with download speeds. 33% are unhappy with customer service. 36% are unhappy with reliability. Those percentages would not indicate enough support to launch a new broadband network. While it may be common to hear complaints about Comcast, overall the surveys don't show massive dissatisfaction.

Support for a New Network. This low dissatisfaction with Comcast is offset by 70% positive to the direct question asking residents if they support the idea of Falmouth getting better Internet access. That response further has 16% of the community that said they might support the idea but need more facts. Only 14% of respondents said they didn't support a new broadband network.

Perceived Value. We expect to see different responses throughout the survey for those who say they are getting a value compared to those that don't perceive value. I looked through the responses to see what else might support one of these two responses. One such response was that those they didn't think they were getting a value today were highly likely to hope that a new network will bring "lower prices than today."

Customer Service. Customer service is not a major concern for the community. Nationwide surveys often suggest that the big cable companies and telephone companies are dreadful at customer service. This survey shows customers don't particularly value better customer service. Only 20% of households would consider changing to a new network due to unhappiness with existing customer service.

More Competition. The driving force for the positive responses to a new network seems to be driven by a desire for more competition. An overwhelming 97% of respondents, including most

of those who oppose a new network said that they would consider changing to a new network if it brought more competition to the market. That's the highest response to that question we've ever seen.

High Cable Penetration. The town has a significantly higher percentage of traditional cable customers (84%) than the country as a whole (68% - 69%). Traditional cable is comprised of those getting cable through a wire to their home or from satellites. This is not unusual, and we've seen similar high responses in several other communities recently. However, a high current cable penetration rate doesn't necessarily translate into those that would buy cable TV from a new network. Only 32% of households said that they would definitely consider buying cable TV from a new provider. This tells us that there are probably a lot of people in the community paying for TV today who are contemplating cutting the cord and watching cable TV online.

Potential Customers on a New Network. The number one purpose for the survey was to provide a starting point for evaluating the feasibility of building a broadband network in the town. That boils down to using the survey to estimate how many customers a new network might attract. Following is how we interpret the responses about buying service from a new network:

- Our experience is that the surveys provide a decent prediction of how a new ISP will do within the first 3 - 5 years after market launch.
- Customers who say they will definitely buy probably will. Every community has some core of customers that don't like the incumbent providers. The customers who say they will definitely buy are dissatisfied with the current providers, really like the idea of having fiber. We typically see between 20% and 30% of customers saying they will definitely change to a new network. Your survey comes in higher than that range with 36% of the respondents ready to immediately change to a fiber network.
- We've always found that around 2/3rds of those that say they will "probably" change will also do so. Some won't overcome the ennui of taking the steps to make the change, and some will be lured with low-priced packages aimed to keep them on the current provider. But overall these respondents have indicated a decent interest in changing providers. In your case, 30% of respondents said they would probably change to a new fiber network.
- The "maybe" respondents are just that. We've always seen that a third of these customers can be gained as customers – but at a cost. This is the part of the market that requires the marketing budget. These customers can be won if you make the effort to explain the benefits of your network and if you have products and prices they find attractive.
- In summary, I think the survey indicates a 5-year target penetration of broadband of 61%. Of course, that prediction assumes that the network is launched on time and on budget and that the service provider does a good job of meeting expectations. There are plenty of opportunities for a new network to make mistakes and underperform.
- CCG has done hundreds of surveys for communities and the 61% result is near the top end of the range of results that we've seen for communities of your size. Surveys in cities of your size more typically predict penetration rates between 45% and 55%. The highest result I remember ever seeing was 65% of respondents who were likely to buy from a new network. In my opinion, this one survey result is highly promising and provide you with a good reason to take the next steps in looking at the feasibility of bringing fiber to the town.
- To summarize the opportunity that is predicted by the survey:
    - A realistic 5-year goal for broadband penetration is 61%.

        - The goal for cable TV is lower at 58%. While this number is true for now, I expect than within the next five years that a lot of the people who say they are interested in cable TV today will cut the cord and drop out of the market. It's an interestingly high prediction in light of the prevalence of cord cutting.
        - The 5-year market penetration for landline telephone is 33%. That's also higher than what I expect since homes continue to drop landlines year after year – but it's what your citizens say today.
    - It's also worth noting that a service provider could perform better than these predicted penetration rates with a concentrated marketing plan. A marketing plan is aimed at the "probably" and "maybe" customers, to convince such customers to buy service.

Variation by Precinct. One of the most intriguing aspects of the survey results is that we gathered results by the nine voting precincts. In your case, these precincts often represent unique and specific different demographics. After riding through the whole town my number one takeaway is that the various neighborhoods in the town are significantly different.

However, in pointing out some of the differences in responses by neighborhood, I must caution that the small size of the number of respondents in each precinct was only 42, and that is not a large enough sample to have a standalone statistical significant. In plain English that says I can't believe the results by precinct in the same manner that I can believe the overall results of the survey. The responses to any question for a precinct may not represent the way that everybody in that precinct might respond to the same question.

With that warning in mind, some of the differences by precinct are probably telling us something of interest. Consider the following topics where the response differed by precinct:

Verizon: We encountered customers that use Verizon for cable TV in precincts 3, 4, and 6. There were enough such responses that it doesn't seem like a case of respondents giving us the wrong answer. We always get a few respondents in every survey who swear they use a service provider that's not even in their market. This tells us that there must be a pocket of Verizon TV in the community. We have a lot of local evidence that Verizon has not built any FiOS in Falmouth. However, the company does serve apartment buildings, condominiums, townhouses and similar properties with large broadband products that are sold to landlords or managing associations and distributed to individual units. We have to guess that there are few such locations in the town located in these three precincts.

Uses of Broadband. Precincts 4 and 6 had a much larger number of households that work from home and that have school children at home. You might want to compare that finding with your knowledge of the community.

Value. Precincts 1, 8, and 9 had the largest percentage of households that had a negative response when asked if they were happy with the value they get for the price they pay for telecom services. We know by the response to other questions covered below that this is due to networks in these precincts that perform worse than the rest of the town. We have found that the coaxial networks used by cable TV companies is not always of uniform quality throughout a community. Perhaps the Comcast wires in these precincts are older or have suffered damage of some sort over time that makes the networks underperform compared to the rest of the town.

Network Outages and Slowdowns. The same three precincts mentioned in the last issue – 1, 8, and 9 - had a much higher percentage of people reporting both outages and slowdowns during the last year. There is something different about the Comcast networks in these portions in town. If the town requires trouble reporting as part of the cable TV franchise it would be interesting to see if problems are centered in these parts of the town.

Support for a New Network. The precincts with the highest level of support for a new network are 1, 3, 4, 8, and 9.

Lower Prices. The sectors where most people hope that a new network brings lower prices are 4, 6, 8, and 9.

Keeping Dollars in the Community. Precinct 1 is the only sector where more than half of the people cited this as a reason to support a new network.

Definitely Would Buy Broadband. Sectors 1 and 4 are the only two sectors where more than 50% of respondents said they would definitely buy broadband from a new network. These same two sectors also have the highest percentage who say they would definitely by cable TV from a new network.

Telephone Service. Sectors 4 and 7 had the largest percentage of those that said they would definitely buy landline telephone.

Trends Post COVID-19. The survey was conducted in the fall of 2019 and reflects pre-COVID opinions of residents. We can't precisely say how the results of the survey would be if taken today, but there are a few industry trends that would likely affect the results we obtained from the survey:

- Increased Demand for Broadband. As students and parents were sent home to work and for school, we saw an increased demand for home broadband. This likely would have resulted in a greater number of homes having broadband, and big ISPs are all reporting increased broadband subscription rates by the second quarter of 2020. The increased demand has also manifested in customers demanding faster speeds. Most ISPs report that a significant number of customers are upgrading to faster broadband packages. We also would expect this would mean more people migrating from Verizon to Comcast to get faster speeds. This would likely result in an even higher number of homes that are interested in fiber broadband.
- Cable TV Penetration. All of the big cable companies are reporting customer losses in 2020. Comcast lost 388,000 cable customers in the first quarter and 477,000 in the second quarter. Roku reported on a market survey conducted in June 2020 that says that most of the losses of cable customers are due to households trying to save money.

C. Other Market Research

Interviews and Business Questionnaires

CCG reached out to businesses in two ways. The EDIC posted a business questionnaire on their web site that asked businesses to tell us about their broadband. We also interviewed larger business and other

stakeholders in the town to learn about broadband issues in more detail. We gave the option to businesses to keep their responses anonymous and a number of them did so.

Here are a few of the things we learned from the questionnaires and interviews:

- In general, practically every business said that they didn't feel like they have any competitive alternatives. Even a few entities using OpenCape fiber say they would love to have a second option.
- The school district has 650 employees serving seven schools and an administration building. The school system serves 3,200 students. The schools report they have world-class broadband provided on fiber by OpenCape. The service is highly reliable and the only outages they can recall is when power goes out. The schools were worried in the spring when students were sent home due to the pandemic. The schools scrambled and provided Chromebooks to any student that needed a home computer. The district only needed about twenty cellular hotspots to provide home broadband for students that did not have home Internet access. The one issue that schools identified is that there are cellular dead spots in some schools where cellphones don't work.
- Falmouth Public Libraries operate three libraries in the town. Two are connected to OpenCape and one to Comcast. The download speeds are good at all three libraries, but the upload speeds are slow at times at all libraries, but particularly the one served by Comcast. The libraries have been closed to the public due to the pandemic and they've been beaming WiFi into the parking lots and they wish the signal were stronger. There are people working in cars and also using picnic tables provided by the library. The library has started a pilot program to let the public check out a few Chromebooks and cellular hotspots – they haven't yet concluded if this something that ought to be made permanent. The library's primary concern during the pandemic is digital literacy. When they are open to the public, they help people with things like applying for unemployment or in working with other government programs. They worry that people will struggle and get left behind.
- We talked to a doctor office with twenty employees that uses Comcast. They report that Comcast has improved significantly over the past few years, which likely is due to Comcast's upgrade to DOCSIS 3.1. The office shares 100 Mbps broadband connection and this is enough broadband most of the time, but there are times when they would like more speed. Like most physicians the office is now doing a lot of telemedicine during the pandemic. They are making telemedicine calls using their cellphones, connected through the Comcast broadband connection using WiFi. It's worth noting that the Cape has the highest percentage of seniors in the population in Massachusetts, which would suggest a higher than average need for telemedicine.
- There were several large employers like the Marine Biological Laboratory that are struggling with employees trying to work from home during the pandemic. They report that employees are having to resort to using cellphones or cellular hotspots when the home broadband connection is not adequate to connect the employees back to the work servers.
- We spoke with the Woods Hole Oceanographic Institution. They employ 1,200 people year-round. They have multiple broadband connections including OpenCape and Comcast and are satisfied overall with the broadband speeds they receive. The biggest concern of the Institution is that they are shut down during any electric outages and during bad weather. They wish they had more resiliency and an alternative during local Internet outages. Much of what they do is in the cloud and they are nearly shut down without Internet access. They still have a lot of employees working from home who are experiencing a wide array of connection problems.
- We spoke with Island Queen Ferry which runs the ferry between Falmouth and Martha's Vineyard. The company has several Internet connections. They use a local company FiberCape

which provides outdoor WiFi for use by visitors to the ferry service. The company also has a Comcast broadband connection which they generally report as working well. The company relies on good broadband because they need to post real-time information for customers about weather conditions or other delays in the ferry schedule. The company also maintains a few Verizon dial-up lines that are used to process credit cards if Comcast isn't working. The company's biggest wish is one provider that could offer a reliable connection and a bundle that includes everything they are buying.

- We talked to Bill Zammer who owns Cape Cod Restaurants and operates two restaurants chains in Falmouth and other nearby towns. He uses Comcast in all three communities and describes the broadband as "on the slower side." He says that Comcast is slow to respond to problems. Mr. Zammer was president of the Chamber of Commerce and thinks that Falmouth needs better broadband infrastructure if it wants to continue to be hot housing market.
- We talked to Bill Hough of the Falmouth Enterprise newspaper. He now has OpenCape and it works great for his needs. He used to use Comcast and had major problems. The service would go down regularly. On one occasion when Comcast was down the newspaper had to use a cellular hotspot to send the newspaper to print – which was incredibly expensive.
- We talked to a business that houses five employees in a shared work facility along with other businesses. All of the businesses share a 100 Mbps connection from Comcast, although tenants are allowed to bring in additional broadband. The biggest problem in the shared workspace is upload speeds. The shared WiFi is "glitchy" and large data files often have to be sent multiple times. None of the tenants can rely on the WiFi for making phone calls, and so they use cellular calling.
- One employer with over fifty local employees is unhappy with the quality of service from Comcast. The business routinely receives only a fraction of the speeds they are paying for. The company says that Comcast customer service is unresponsive. As an example, it took over a month to add an additional telephone line. The company says that poor broadband is negatively affecting the business. Almost all of the software used by the company is in the cloud, including software used to arrange for shipping products to customers. They routinely have cloud communications problems or broadband outages that stop them from shipping on time. The company would like faster Internet, but also redundancy, meaning they would like a backup connection using another ISP. However, they don't feel they have competitive alternatives.
- A local photographer works from his home and can only get Verizon DSL. Photographers routinely share large data files back and forth between clients. The broadband connection is so poor that he often has to go to a friend's home or the library to get his work done.
- We heard from half a dozen realtor offices that ranged in size from two to over forty employees. Realtors routinely exchange photograph albums which are large data files. The realtors all said that their download broadband connections were adequate for exchanging files. They often had problems sending large data files. Several of the larger realtors said that their broadband connection was not adequate at times when there were a lot of realtors in the office at the same time.
- We heard from two people in the medical field that often work from home. They both said that their Internet connection was not adequate to process medical data files. The privacy concerns associated with medical records require connecting through HIPAA-approved software connections on secure VPNs, and they say that routinely they have to redo work and send files multiple times due to the variance in their Comcast data connections.
- We talked to one business owner who has Comcast at home in Falmouth but has Verizon FiOS at a home off the Cape. He said the different between the two broadband services is startling.

We asked business in Falmouth how they used the Internet and got the following responses:

- To Communicate with Customers. Businesses routinely have portals that make it easy for customers to place and track orders and to communicate with the business. Inadequate broadband means lower sales. The old days of calling purchasing agents is gone and most commerce between companies has become automated – which improves accuracy and speeds up the ordering process. Businesses that operate busy ecommerce ordering sites need big amounts of bandwidth to make sure that all customers have a successful purchasing experience.
- To Communicate with Vendors. Businesses also routinely use the portals of their own vendors to buy whatever they need to operate.
- To Communicate with Other Branches of the Company. A number of businesses in Falmouth are part of larger corporations and maintain open data connections to communicate with other parts of the company and with headquarters.
- Working in the Cloud. It's now common for companies to work in the cloud using data that's stored somewhere offsite. This can be in one of the big public clouds like the ones offered by Amazon, Google, or Microsoft or it can be a private cloud available only to employees of the business. This is the change in the ways that companies operate that has probably created the most recent growth in bandwidth. Much of the routine software that companies use now works in the cloud, meaning that productivity comes to a halt when the Internet connection isn't working.
- Security Systems. Businesses often have their security monitored by offsite firms. Security today also means the use of numerous video cameras (and the ensuing video streams) used to monitor the inside and outside of a business.
- Sending and Receiving Large Data Files. Most businesses report that the size of data files they routinely transmit and receive have grown significantly larger over the last few years. Some of the businesses in Falmouth report routinely swapping terabit-sized files.
- VoIP. Many businesses now provide the voice communications between their various branches using Voice over IP. A reliable VoIP system needs to have dedicated bandwidth that is guaranteed and that won't vary according to other demands for bandwidth within the business.
- Communicating via Video. Communicating via video was building momentum during the last year but has exploded as the business world has migrated to Zoom and similar video platforms.
- Email and Advanced Communications. While many businesses still rely on email, many have gone to more advanced communications systems that let parties connect in a wide variety of ways. Businesses are using collaborative tools that let multiple employees from various locations work on documents or other materials in real time.
- Supporting Remote Employees. Supporting employees that work from home is a major new requirement for many businesses. Communicating with remote employees most generally is done by creating a virtual private network (VPN) connection with each employee. For the business that means establishing both a dedicated upload and download link to each remote employee. These connections can vary between 1 – 3 Mbps per second in both the upload and download directions. The big challenge for companies using Comcast is the limited size of the upload connection.
- Data Back-up. Companies are wary of hacking and ransomware and routinely maintain several remote copies of all critical data to allow them to restore data after a problem.

Impact of Poor Broadband for Businesses

There are numerous consequences of poor broadband for businesses. While some businesses have unique and specific requirements, there are a number of problems caused by poor broadband that affect most businesses. Some of the larger businesses in town are served with fiber from Open Cape. However, most businesses in the community have the same broadband choices as residents.

Impact on Day-to-day Operations. The list immediately above describes the many routine ways that businesses in Falmouth use broadband. Businesses without adequate bandwidth must forgo or compromise on how they communicate with the world and function day-to-day. Many of the businesses in Falmouth told us that they felt constrained from doing everything they could with broadband.

Entrepreneurship. Every community has success stories of companies that started in a home that are now significant employers in the community. Many communities have developed business incubator sites to support and promote start-up businesses. Good broadband is essential for a start-up ecosystem.

Smart Factories. The pandemic uncovered major problems in the US supply chain and both political parties are now talking about a big government push to bring manufacturing back to the US, particularly in vulnerable areas like medicines and electronics.

Over the past decade the US has created over 900,000 jobs in newly built "smart" factories. Smart factories need a lot of bandwidth for functions like the following:

- Programmable Robots. Automated factories are using robots that can perform a range of different tasks that can be directed by software to perform the need task at the right time.
- Collaborative Robots (Cobots). Collaborative robots work with human operators to take over time-consuming or high-precision work to enable the human operator to concentrate on the tasks that require judgement and experience.
- Precision Manufacturing. Robots can be used to perform high-precision tasks that were difficult and time-consuming with human operators.
- Making and Handling Customer Materials. Factories are manufacturing modern materials like carbon nanotubes on site as part of the manufacturing process.
- Performing Complex Chemical Processes. Automated machines are being used to handle the creation of complex chemicals that are either dangerous to handle or that require highly precise processes to create.
- Remote Instructions. Robots can be directed by remote engineers or technicians from a different location when that's needed for custom tasks.
- Equipment Monitoring. Sensors are used to monitor machinery and robots to predict machine failures and to dispatch repairs or order replacement parts before they are needed.

Economic Development and Jobs: Reliable and affordable broadband is still one of the key elements in traditional economic development to lure new companies to a community or to keep existing companies from leaving. As vital as broadband is to residents it's even more vital to businesses.

It's probably a minor point but building a fiber network in Falmouth brings roughly twenty new high-paying jobs to the community. It's been our experience that a new fiber network does not decrease the workforce for existing ISPs.

Businesses want more than just fast broadband. They often require multiple feeds of broadband from different ISPs, on diverse routes to guarantee that they don't lose connectivity. There are several businesses in Falmouth that require a diverse and redundant source of broadband.

Realtor / Rental Agent Survey

One of the most interesting challenges of understanding broadband demand in Falmouth is to get a feel for how the tourist rental market feels about broadband issues. The community grows from a population of 30,000 in the offseason to as much as 100,000 during the summer. The vast majority of tourists stay in rented houses and apartments.

We created an online survey for realtors / rental agents asking about broadband and cable TV. This was not a statistically valid sample and these results can't be easily applied to all renters in Falmouth, but the results are still interesting. The rental agent survey produced the following results:

Six rental agents took the online survey. They handled rentals in all parts of Falmouth including Falmouth proper, East Falmouth / Waquoit, West and North Falmouth, and Woods Hole.

The rentals varied by type as follows:

One Week or Less	44%
One Month	3%
All Summer	16%
Nine Months	16%
All Year	23%

Realtors reported that 80% of renters ask about broadband when considering a rental. 57% ask about cable TV.

Realtors report that 62% of the rental properties include Internet as part of the rent. The remainder, mostly the longer-term rentals, expect renters to buy their own Internet. 57% of rentals include cable TV.

The realtors report that 20% of renters have made a complaint about the Internet. The most common complaint is consistency.

All of the realtors said it would be easier to rent properties if they included high-speed fiber broadband. Several realtors noted that Internet access was of more importance to "higher end" renters.

Speed Tests

CCG created an online speed test that was published on the EDIC website. The primary purpose of the speed test was to see if residents and businesses were getting the broadband speeds they subscribed to.

The overall purpose of the speed tests is to judge the overall quality of broadband in the market. For example, CCG has conducted similar speed tests in markets where Comcast is the incumbent cable company, and we've seen markets where the speeds delivered are faster than advertised and other

markets where the speeds are slower. This is largely a qualitative test that tells about the quality of the overall network within Falmouth.

Speed tests are not a perfect measurement tool for several reasons:

- A speed test only measures the speed of a ping and a short-term connection under a minute between a user and the test site router used by the speed test. That doesn't necessarily indicate the speed of every activity on the web such as downloading files, making a VoIP phone call, or streaming Netflix.
- Every speed test on the market uses a different algorithm to measure speed. In Falmouth we used the speed test from Ookla, which is one of the most popular speed tests. Ookla's algorithm discards the fastest 10% and the slowest 30% of the results obtained. In doing so they might be masking exactly what drove someone to take the speed test, such as not being able to hold a connection to a VoIP call. Ookla also multithreads, meaning that they open multiple paths between a user and the test site and then average the results together.
- A speed test has no way to know if a customer has network issues within the home such as problems with a home WiFi router or faulty wires inside a home. A slow speed test doesn't always mean that the ISP has a slow connection.
- Speed change throughout the day, and anybody that takes multiple speed tests in the same day will see this. Most broadband connections today use shared bandwidth, meaning that multiple customers in a neighborhood share the bandwidth in some manner. When a neighborhood node is busy, the speed tests will be slower.
- Some ISPs use something called "burst" technology. This provides a fast Internet connection for one or two minutes. ISPs know that a large majority of Internet activities are of a short duration – things like opening a web page, downloading a file, reading an email, or taking a speed test. The burst technology increases the priority of a customer during the burst time window and the Internet connection then slows down when the burst is over. This raises an interesting question – what's the Internet speed of a customer that gets 100 Mbps during the burst and something slower than that after the burst – there is no consensus in the industry.

Latency. In addition to upload and download speeds, the speed tests also measured latency. Latency basically means delay in receiving a signal from the Internet. There are a lot of underlying causes for delays that increase latency – the following are primary kinds of delays:

- Transmission Delay. This is the time required to push packets out the door at the originating end of a transmission. This is mostly a function of the kind of router and software used at the originating server. This can also be influenced by packet length, and it generally takes longer to create long packets than it does to create multiple short ones. These delays are caused by the originator of an Internet transmission.
- Processing Delay. This is the time required to process a packet header, check for bit-level errors and to figure out where the packet is to be sent. These delays are caused by the ISP of the originating party. There are additional processing delays along the way every time a transmission has to "hop" between ISPs or networks.
- Propagation Delay. This is the delay due to the distance a signal travels. It takes a lot longer for a signal to travel from Tokyo to Baltimore than it takes to travel from Washington DC to Baltimore. This is why speed tests are usually created to find a nearby router to ping so that they can eliminate latency due to distance. These delays are mostly a function of physics and the speed at which signals can be carried through cables.

- Queueing Delay. This measures the amount of time that a packet waits at the terminating end to be processed. This is a function of both the terminating ISP and also of the customer's computer and software.

Total latency is the combination of all of these delays. You can see by looking at these causes that poor latency can be introduced at multiple points along an Internet transmission, from beginning to end.

The technology of the last mile is generally the largest factor influencing latency. A few years ago the FCC did a study of the various last mile technologies and measured the following ranges of performance of last-mile latency, measured in milliseconds: fiber (10-20 ms), coaxial cable (15-40 ms), and DSL (30-65 ms). These are measures of latency between a home and the first node in the ISP network. It is these latency differences that cause people to prefer fiber. The experience on a 30 Mbps download fiber connection "feels" faster than the same speed on a DSL or cable network connection due to the reduced latency.

It is the technology latency that makes wireless connections seem slow. Cellular latencies vary widely depending upon the exact generation of equipment at any given cell site. But 4G latency can be as high as 100 ms. In the same FCC test that produced the latencies shown above, satellite was almost off the chart with average latencies of 650 ms.

A lot of complaints about Internet performance are actually due to latency issues. It's something that's hard to diagnose since latency issues can appear and reappear as Internet traffic between two points uses different routing. But the one thing that is clear is that the lower the latency the better.

Results of the Speed Test. 125 people took the speed test. With the above caveats in mind, following are the results of the speed tests we received:

Comcast

As would be expected, since most homes in the community use Comcast, most of the speed tests were from the Comcast network.

There was a wide range of speeds reported on Comcast – more of a range than we usually see on cable company broadband networks. The results for the 114 speed tests for Comcast are as follows:

Comcast Download Speed	
0 – 10 Mbps	5
11 – 20 Mbps	9
21 – 30 Mbps	6
31- 40 Mbps	4
41 – 50 Mbps	8
51 – 75 Mbps	9
76 – 100 Mbps	12
101 – 150 Mbps	13
151 – 200 Mbps	10
201 – 300 Mbps	20

301 – 400 Mbps	6
401 – 500 Mbps	5
500 – 600 Mbps	1
600 Mbps +	6

We have been doing similar feasibility studies for years and we have never seen this kind of range of speed test results from a Comcast network. We know that Comcast has upgraded to DOCSIS 3.1 technology because 11% of those taking the speed tests are reporting speeds faster than 300 Mbps download.

But the results are still surprising. 23% of customers are getting speeds under 50 Mbps, with 18% of all customers getting speeds under 30 Mbps. 41% of everybody taking the speed test saw download speeds under 100 Mbps.

There are a few possible explanations for the slow speeds on the Comcast network. The most likely explanation is that Comcast has never upgraded some of the original network configuration since they purchased the network from Adelphia. When comcast first got the network, it was likely that neighborhood nodes were large with 400 up to 1,000 customers in each node. Those large nodes are the primary reason that download broadband speeds bogged down in the evenings a decade ago – when people first started using the web to watch video the network would get overloaded since there were too many customers sharing the bandwidth.

Since then Comcast has certainly decreased the size of nodes. This is done by building a fiber to serve clusters of perhaps 150 homes or less. When nodes are that small it's rare to see video freezing – and we didn't hear reports of many problems in watching Netflix.

However, we think it's likely that Comcast didn't fully upgrade to small nodes. We are betting that they are still using a network configuration called cascading. This is where a fiber is brought to one neighborhood and then shared with a second, and perhaps even a third or fourth neighborhood. This configuration doesn't have the same characteristics of having large nodes. Instead, the customers in the first node where the fiber connects have good broadband speeds, but the subsequent nodes perform worse. We've seen this situation in HFC networks that demonstrate the speed issues we see in Falmouth. Some parts of the town have great speeds and others do poorly. This is something Comcast could fix by building more fiber so that each node has its own fiber connection.

It's also possible that the more basic characteristics of the Comcast network varies throughout the town. There could be neighborhoods with older coaxial cable and others that were built later or upgraded at some time in the past. There could be neighborhoods with high quality coaxial cable and others with problems that invite interference.

It's possible that some customers are grandfathered with older and slower products. For instance, a few people taking the speed test told us that they subscribe to 25 Mbps broadband. That product hasn't been available to a new customer for many years, but Comcast might be allowing customers to keep the slower speeds, and likely a lower price. Typically, if such customers change any product at Comcast they get upgraded to the current broadband speeds but also prices. The big cable companies don't have the same policies everywhere – there may be

Comcast markets that have grandfathered products while others do not – we think it's up to the discretion of the regional managers.

It's also possible that customers still have an old DOCSIS 3.0 modem that won't go any faster. Most cable companies are pretty good at swapping out modems with technology upgrades, but it's possible that there are customers paying for speeds over 100 Mbps who are stuck with old modems that can't deliver that much speed. We have not heard many complaints nationwide about Comcast doing this – but it's possible.

Finally, there will always be some customers in a speed test that get slow speeds because of issues in the home such as slow WiFi. For example, customers may have supplied their own WiFi and not upgraded for a decade. But it's highly unlikely this could explain the large number of customers who are getting slow speeds – we rarely see more than a few percentage of a market with this issue.

We also saw a range of upload speeds reported for Comcast as follows:

Comcast Upload Speeds	
0 – 5 Mbps	15
6 – 10 Mbps	45
11 – 15 Mbps	26
16 – 20 Mbps	7
21 – 30 Mbps	3
31 – 40 Mbps	5
41+Mbps	9

Like with download speeds, we were surprised to see 14% of customers with upload speeds under 5 Mbps, with some speeds as slow as 2 Mbps and 3 Mbps. 55% of customers reported upload speeds under 10 Mbps. 78% of all customers reported upload speeds of 15 Mbps or slower. This is pretty typical compared to what we see on other cable company networks in other communities. As described in several other places in this report, upload speeds have suddenly become a concern for homes where multiple people try to take office or schoolwork home.

Verizon

Verizon serves the community with what looks to be older early generation DSL over telephone copper wireless. We only got eleven speed tests from Verizon customers. All of the tests show slow speeds as follow:

DSL Download Speed	
0 – 2 Mbps	8
2 – 5 Mbps	2
11 – 15 Mbps	1

DSL Upload Speed	
Under 1 Mbps	11

The average download speed was 2.6 Mbps. One customer reported a download speed of 11 Mbps. The average upload speed was 0.6 Mbps. The average latency is 39 milliseconds.

D. Broadband GAP Analysis

A broadband gap is a situation where some customers have better broadband than others. This report will look at the different kinds broadband gaps as described below.

- The Gap in Broadband Speeds. How the broadband speeds in Falmouth compare to other places.
- The Gap in Broadband Availability. Homes that don't use the Internet.
- The Gap in Broadband Affordability. In every community there are households that don't subscribe to broadband because of the cost.
- The Gap in Computer Ownership. There are households that don't subscribe to broadband because they can't afford a computer.
- The Gap in Broadband Skills. There are citizens who don't buy broadband because they lack the skills needed to operate in the digital age.
- Future Broadband Gaps. Even where there is adequate broadband today, we can look forward to the natural progression of technology that will create new broadband gaps that don't exist today.

After describing the different broadband gaps, this report will look at the consequence of the broadband gaps and will ask the question if there are any practical solutions to the broadband gaps that the town could facilitate.

The Gap in Broadband Speeds

Duopoly Competition

Any discussion of a broadband gap in a town the size of Falmouth has to begin with a discussion of duopoly competition. Duopoly competition refers to a market with only two primary competitors. In broadband, markets that are divided between a telephone company and a cable company meets the classic definition of a duopoly.

A duopoly market often shares a lot of the same characteristics of a monopoly market. In duopoly markets the two competitors rarely compete on price, with the result being high prices from both competitors and good margins for both companies. Duopoly providers generally don't concentrate on customer service since customers only have two choices.

If you look back to 2000, there was true duopoly competition in urban areas. At that time, the capability of telephone company DSL and cable company modem service was similar in capability and it was hard at the customer end to distinguish one service from the other. The two competitors mostly advertised about how their broadband was superior to its competitor, but there were no price wars where telcos or cable companies dropped prices to try to win a share of the market. In most places in the US the telephone companies hit the broadband market first, and in the early days the telcos had more broadband customers than cable companies.

However, over time, the cable broadband products improved faster than telephone company DSL. Cable companies currently offer speed that approach gigabit speeds and the base broadband product is usually between 100 Mbps and 200 Mbps. DSL has improved a lot since 2000, but the fastest DSL today in most markets delivers a little less than 50 Mbps – in Falmouth, most DSL delivers speeds under 15 Mbps.

A lot of economists say that the cable companies have won the duopoly battle, due entirely to having faster broadband speeds. That can certainly be seen in Falmouth where the residential survey showed that Comcast has 83% of broadband market to only 8% for Verizon. Households in town have clearly migrated over time to Comcast. This switch from DSL continues and nationwide statistics show DSL customers continue to switch to the cable company.

Technology Matters

To a large degree, the broadband speeds available to customers is dependent upon the technology used to deliver the broadband. The report discusses various technologies in more detail in the engineering portion of the report.

The general speeds available on various technologies is as follows:

- DSL delivered on one copper pair can deliver speeds as fast as 25 Mbps for up to two miles from the DSL transmitter, assuming the copper is in good condition and other factors are ideal. There are slower versions of DSL deployed in the networks that might have maximum speed capability of 3 Mbps, 6 Mbps, 12 Mbps, or 16 Mbps. In Falmouth it looks like the DSL is older technology.
- DSL delivered on two bonded copper pairs can deliver twice the speeds. This technology usually only uses the latest types of DSL and has maximum speeds around 50 Mbps.
- The hybrid-fiber coaxial systems from cable companies can bring significantly faster broadband speeds. Networks using the DOCSIS 3.0 standard can deliver speeds up to perhaps 400 Mbps. Networks upgraded to the most recent DOCSIS 3.1 standard can deliver speeds up to a gigabit. Cable networks are limited due to the technology of offering upload speeds that can be not greater than 1/8 of the total broadband delivered. Most cable companies have elected to hedge the networks towards providing faster download, to the detriment of faster upload speeds.
- High orbit satellite broadband can deliver speeds as fast as 75 Mbps. The problem with this broadband is that the satellites are so far above the earth that there is a lot of delay (latency) in the signal and it's hard to do real-time web activities like streaming video, connecting to a corporate WAN or a school server, making VoIP calls, or even shopping on some web sites.
- Fixed point-to-multipoint wireless is capable of speeds up to 100 Mbps, although the equipment and configuration of most networks brings speeds significantly less than this, sometimes as slow as only a few Mbps. We are not aware of anybody offering this technology in Falmouth.
- Fiber networks deliver the fastest broadband. Fiber networks with the older BPON technology are limited to speeds of about 200 Mbps per system. More modern GPON technology can deliver speeds up to a symmetrical gigabit (same speed up and down). There are newer kinds of fiber-to-the-home technology that offer speeds up to 10 Gbps.

The speeds delivered by some of these technologies can differ by customer within a town. As an example, the speed of Verizon DSL to a given customer can be affected by:

- How far that customer lives from a DSL transmitter (called a DSLAM).
- The size of the copper wire serving the customer (sizes typically vary between 16-gauge and 24-gauge copper).
- The age and quality of the copper (copper wire slowly degrades over time, particularly if the copper comes into contact with the elements or with longstanding water).
- The quality of the telephone wiring inside of a home (this varies a lot, particularly for wires that were installed by the homebuilder rather than by the telco).
- The type of DSL electronics used to serve a customer. There are still older DSL technologies in use that have maximum download speeds of only a few Mbps and newer DSL that can deliver speeds as fast as 48 Mbps.
- The backhaul network used to provide bandwidth to a feed the DSL network. DSL is like most broadband technologies and bandwidth is shared between users in a given neighborhood. If the total usage demanded by the neighborhood is greater than the bandwidth supplied to the neighborhood, then everybody gets slower speeds while the network is over-busy.
- The DSL network has additional bandwidth choke points, which are places in the network that can restrict customer bandwidth if not engineered properly. For example, the neighborhood DSL hubs might contain older technology or not be fully stocked with the circuit cards needed to provide the best service.
- And finally, speeds can be impacted by how a customer gets broadband to devices. For example, an old WiFi router can cut down the speed between what is delivered to the home and what makes it to computers and other devices inside the home.

All of these factors mean that DSL speeds vary widely. Two adjacent homes can have a significantly different DSL experience.

FCC Definition of Broadband

In 2015, the FCC established the definition of broadband as 25/3 Mbps (that's 25 Mbps download and 3 Mbps upload). Prior to 2015 the definition of broadband was 4/1 Mbps, set a decade earlier. The FCC defines broadband in order to meet a legal requirement. Congress established a requirement for the FCC in Section 706 of the FCC governing rules that the agency must annually evaluate broadband availability in the country. Further, the FCC must take action if broadband is not being deployed in a timely manner. The FCC report the state of broadband to Congress every year.[3] In these reports the FCC compiles data about broadband speeds and availability and proffers an opinion on the state of broadband in the country. In every report to date, the FCC has acknowledged that there are broadband gaps of various kinds, but the FCC has never determined that the problems are so bad that they need to take extraordinary measures to close any broadband gaps.

The FCC didn't use empirical evidence like speed tests in setting the definition of broadband in 2015. They instead conducted what is best described as a thought experiment. They listed the sorts of

[3] The FCC report to Congress for 2019 can be found at https://docs.fcc.gov/public/attachments/FCC-19-44A1.pdf.

functions that a "typical" family of four was likely to engage in, and then determined that a 25/3 Mbps broadband connection was fast enough to satisfy the broadband needs of a typical family of four.

The FCC asked again in 2018 if 25/3 Mbps is an adequate definition of broadband. They concluded that 25/3 Mbps is still an adequate definition of broadband. There were numerous filings made in that docket that argued that the definition of broadband should be increased.

The Upload Speed Crisis

The COVID-19 pandemic has exposed a new broadband problem that was never much discussed before. Many homes that thought they had good broadband found that they were unable to function when multiple people in the home tried to simultaneously connect to work or school servers. We know that this is a problem in Falmouth because we heard directly from people who had problems working and doing schooling from home during the pandemic. Not every home has this problem – just homes with relatively slow upload bandwidth where multiple people try to work using the web at the same time.

Perhaps the easiest way to describe the problem is with a real-life anecdote. I have a colleague who was sent home to work along with her husband and two teenagers. The two adults are trying to work from home and the two kids are supposed to be online keeping up with schoolwork.

The family has a broadband connection from a cable company with a download speed over 100 Mbps, but an upload speed that hovers around 10 Mbps. On top of their normal broadband usage, the family suddenly had to make a lot of new connections. Each of them needs to create a VPN to connect to their office or school servers. They are also each supposed to be connecting to Zoom or other online services for various meetings, webinars, or classes. The family also needed to make several telemedicine connections during the pandemic. The home still continues to need bandwidth for normal functions like reading emails or backing up files up in the cloud. Each member of the family also has their cellphones automatically connect to WiFi when they walked into the home.

How Much Upload Speed is Needed? The upload speed crisis is relatively new and started to affect millions of homes after the onset of the pandemic when people tried to work from home and connect to schools from home. The problem has always been familiar to people who need fast upload broadband like doctors, photographers, engineers, architects, and others that have tried to work from home.

The problem is still so new that there is not yet any industry consensus about the amount of upload bandwidth that is needed in a home. But we understand many of the individual needs for upload bandwidth:

- Connecting to a work server or a school server can require between 1 Mbps and 2 Mbps, dedicated upload speed, depending upon the specific software used by a given school or business – meaning that upload bandwidth us used during the duration of the connection and can't be used for any other purpose in the home. These connections are usually, but not always made by creating a virtual private network (VPN) connection that locks in the connection for as long as there is sufficient bandwidth. Typically, if bandwidth falls below the needed amount the connection will drop.

- Ever online video service is a little different, but all require a stead upload signal to establish a video chat. Consider the bandwidth needs described by Zoom on its web page.[4] Zoom says that a home should have a 2 Mbps connection, both upload and download to sustain a Zoom session.
- Telemedicine connections tend to be even larger than the connections to work and school servers, and also require the simultaneous use of both upload and download bandwidth.
- Just before the onset of the pandemic several major gaming platforms moved games online into the cloud. Historically, gamers purchased or download software that ran games on local computers or game boxes. Moving games to the cloud makes them available to anybody on a wider range of devices. But putting the games in the cloud means that games are played in data centers and the command and images for the games are transmitted to gamers in real time over broadband.
- One of the biggest uses of upload bandwidth is still machine-to-machine traffic. This is communications generated by computers to the cloud. Most homes now use the cloud extensively to backup up everything done on home computers. Pictures, videos, and work files are automatically updated to web storage. Computer software constantly checks to see if updates are needed. Apps loaded onto computers and phones constantly send data about users to the cloud. This traffic is immense and Cisco estimates that by 2022 that 51% of all traffic on the web will consist of computers communicating with each other without any human direction.
- There has also been a big explosion in the use of home video cameras. Sending cameras images outside of the home to cloud storage or to be viewed when people are away from home requires significant upload bandwidth.

The simplistic way to quantify the bandwidth needs is to add up the various uses. For instance, if four people in a home each wanted to have a different Zoom conversation, the home would need a simultaneous connection of around 8 Mbps both up and down. But bandwidth use in a house is not that simple, and a lot of other factors contribute to the quality of bandwidth connections within a home. Consider all of the following:

- WiFi Collisions. WiFi networks can be extremely inefficient when multiple people are simultaneously trying to use the same WiFi channels. Today's version of WiFi only has a few channels to choose from, so multiple connections on the WiFi network interfere with each other. It's not unusual for the WiFi network to add a 20% to 30% overhead, meaning that collisions of WiFi signals effectively waste usable bandwidth.
- Lack of Quality of Service (QoS). Home broadband connections don't provide quality of service, which means that homeowners are unable to prioritize data streams. QOS is a technology that might let a customer prioritize a connection like a school connection. This would mean that connection would get priority, to the detriment of all other connections at the home. Without QoS, insufficient bandwidth affects all broadband usage within a home. This is easily demonstrated if somebody in a home tries to upload a big data file while somebody else is using Zoom – the Zoom connection can suddenly not have enough bandwidth available and will either freeze or drop the connection – as millions of Zoom users experienced.
- Shared Neighborhood Bandwidth. Unfortunately, a home using DSL or cable modem broadband doesn't only have to worry about how others in the home are using the bandwidth, because bandwidth is also shared with everybody else using the same ISP in their neighborhood. As the bandwidth demand for the whole neighborhood increases, the quality of the bandwidth available

[4] https://support.zoom.us/hc/en-us/articles/204003179-System-Requirements-for-Zoom-Rooms

to every home degrades. It's possible for the bandwidth connection to a whole neighborhood to be maxed out – which result in the inability of anybody else to make an outgoing connection.

- Physical Issues. ISPs don't want to talk about it, but events like drop wires swinging in the wind can affect a DSL or cable modem connection. Cable broadband networks are also susceptible to radio interference – your connection will get a little worse when somebody is operating a blender or microwave oven.
- ISP Limitations. All bandwidth is not the same. For example, the upload bandwidth in a cable company network uses the worse spectrum inside the cable network – it uses the frequency that is most susceptible to interference. This never mattered in the past when customers cared about download bandwidth, but an interference-laden 10 Mbps upload stream is not going to deliver a reliable 10 Mbps connection.

The family in question quickly figured out that their bottleneck was upload speeds. They discovered that they could not all work at the same time – and so they had to take turns using the Internet for school or work. The problem was even more aggravating because they sometimes ran into problems even when only two of them were working at the same time. It appears that that the amount of upload bandwidth available to the home varies during the day, likely as the result of factors outside of the home.

Before the pandemic, this family thought they had great broadband. They never had a problem before the pandemic, except for a few times when the teenagers were running multiple games in the cloud at the same time. But suddenly, the broadband connection was not adequate, and the family looked around for alternatives. Unfortunately, they didn't find any broadband products available for their home that are faster than the cable company.

The nearest analogy to this situation harkens back to traditional landline service. We all remember times, like after 911, when you couldn't make a phone call because all the circuits were busy. That's what's happening with the increased use of VPN connections to school and work servers. Once the upload path from a neighborhood is full of VPNs, nobody else is in the neighborhood can grab a VPN connection until somebody "hangs up."

What Does the FCC Say About Upload Bandwidth? In August of 2020 the FCC adopted its *Sixteenth Broadband Deployment Report Notice of Inquiry*[5] that is used to report the state of broadband to Congress. On the opening page of that document the FCC makes the extraordinary statement that 85% of the home in the US can buy broadband with speeds of 250 / 25 Mbps.

The FCC makes this claim based upon the data provided to it by the country's ISPs on Form 477. We know the data reported by the ISPs is badly flawed in overreporting download speeds, but we've paid little attention to the second number the FCC cites – the 25 Mbps upload speeds that are supposedly available to everybody. I think the FCC claim that 85% of homes have access to 25 Mbps upload speeds is massively overstated.

The vast majority of the customers covered by the FCC statement are served by cable companies using hybrid fiber-coaxial technology. I don't believe that cable companies are widely delivering speeds greater than 25 Mbps upload. I think the FCC has the story partly right. I think cable companies tell

[5] https://docs.fcc.gov/public/attachments/FCC-20-112A1.pdf

customers that the broadband products they buy have upload speeds of 25 Mbps, and the cable company's largely report the marketing speeds on Form 477.

But do cable companies really deliver 25 Mbps upload speeds? We saw in Falmouth that most Comcast customers do not see upload speeds greater than 25 Mbps.

It's fairly easy to understand the upload speed capacity of a cable system. The first thing to understand is the upload capacity based upon the way the technology is deployed. Most cable systems deploy upload broadband using the frequencies on the cable system between 5 MHz and 42 MHz. This is a relatively small amount of bandwidth and it also sits at the noisiest part of cable TV frequency. I remember back to the days of analog broadcast TV and analog cable systems when somebody running a blender or a microwave would disrupt the signals on channels 2 through 5 – the cable companies are now using these same frequencies for upload broadband. The DOCSIS 3.0 specification assigned upload broadband to the worst part of the spectrum because before the pandemic almost nobody cared about upload broadband speeds.

The second factor affecting upload speeds is the nature of the upload requests from customers. Before the pandemic, the upload link was mostly used to send out attachments to emails or backup data on a computer into the cloud. These are largely temporary uses of the upload link and are also considered non-critical – it didn't matter to most folks if a file was uploaded in ten seconds or five minutes. However, during the pandemic, all of the new uses for uploading require a steady and dedicated upload data stream. People now are using the upload link to connect to school servers, to connect to work servers, to take college classes online, and to sit on video call services like Zoom. These are critical applications – if the broadband fails then the user loses the connection. The new upload applications can't tolerate best effort – a connection to school either works or it doesn't.

The final big factor that affects the bandwidth on a cable network is demand. Before the pandemic, a user had a better chance of hitting 25 Mbps upload because they might have been one of a few people trying to upload at any given point in time. But today a lot of homes in a neighborhood are trying to use uploading at the same time. This matters because a cable system shares bandwidth both in the home, but also in the neighborhood.

The upload link from a home can get overloaded if more than one person tries to connect to the upload link at the same time. Homes with a poor upload connection will find that a second or a third user cannot establish a connection. The same thing happens at the neighborhood level – if too many homes in a given neighborhood are trying to connect to upload links, then the bandwidth for the whole neighborhood starts to fail. Remember a decade ago that it was common for videos to freeze or pixelate in the evening when a lot of homes were using broadband? The cable companies have largely solved the download problem, but now we're seeing neighborhoods overloading on upload speeds. This results in people unable to establish a connection to a work server or being booted off a Zoom call.

The net result of the overloaded upload links is that the cable companies are not and cannot deliver 25 Mbps to most homes during the times when people are busy on the upload links. The cable companies have ways to fix this – and most fixes mean expensive upgrades. Meanwhile, if the cable companies were honest, they would not be reporting 25 Mbps upload speeds to the FCC.

Microsoft Speed Data

Microsoft is in an interesting position when it comes to looking at broadband speeds. The vast majority of computers in the country download sizable upgrade files from Microsoft. Even many Apple computers are loaded with Microsoft Office products like Word, Excel, and PowerPoint.

Microsoft decided a few years ago to record download speeds of software upgrades. There is probably no better way to measure a broadband connection than during a big file download. Most speed tests only measure broadband speeds for 30 seconds to a minute. A lot of ISPs in the country deploy a technology generally referred to as "burst." This technology provides a faster download for a customer for the first minute or two of a web event. It's easy for a customer to know if their ISP utilizes burst, because during a long download, such as updating Microsoft Office, the user can see the download speeds drop to a slower speed after a short time. This technology has great benefits to customers since the large majority of web activities don't take very long. When customers visit a website, open a picture, or even take a speed test, the customer only needs bandwidth for a short time to complete most web tasks. The burst technology gives customers the impression that they have a faster download speed than they actually have (or it could be conversely argued that they have a fast speed, but just for a minute or two).

Microsoft measured downloads starting in September 2018, and found:

- The 2018 FCC data claimed that 24.7 million people in the US don't have access to download speeds of at least 25/3 Mbps. In September 2018 Microsoft claimed that 162.8 million people were downloading data at speeds slower than 25/3 Mbps.
- The FCC claimed in 2018 that 98.6% of the homes in Barnstable County had access to broadband of at least 25/3 Mbps. In September 2018 Microsoft said that only 71.8% of Internet connections in the county were at broadband of at least 25/3 Mbps.

It's important to note that the FCC and Microsoft are not measuring the same thing. The FCC is measuring the percentage of homes that have access and can purchase 25/3 Mbps broadband. Microsoft is measuring the actual speeds of downloads. There are a few reasons why the speeds might be different. For example, some people opt to buy broadband products slower than 25/3, even when faster broadband is available. In Falmouth, everybody using Verizon DSL will be slower than the 25/3 Mbps speed. Some households receive slower speeds due to issues in the home like poor-quality WiFi routers.

The Gap in Broadband Availability

The FCC reports that broadband adoption for the country is around 87%. Falmouth is higher than average with 91% of respondents to the survey having a landline broadband connection. That means that 9% of the homes of full-time residents don't have a landline broadband connection. Numerous studies and surveys have asked people why they don't buy broadband when it's available.

John B. Horrigan published a paper[6] earlier this year titled *Measuring the Gap* that makes the point that the reasons that homes don't have broadband are complicated. There have been studies over the years that have tried to pin down the primary reason that homes don't have broadband, but by doing so the studies have glossed over the fact that most homes have multiple reasons for not having broadband.

[6] https://www.digitalinclusion.org/blog/2020/02/11/measuring-the-gap-by-john-horrigan/

A good example of this is a Pew Research Center survey in 2019 that explored the issue. In that survey:

- 50% of respondents said that high prices are a reason for not having broadband, but only 21% said price is the primary reason.
- 45% of respondents said they relied on smartphones that could do everything they need, but only 23% said that was the primary reason for not buying broadband.
- 43% said they were able to get access to the Internet from a source outside the home, but only 11% gave that as the primary reason.
- 45% said that the cost of a computer is too expensive, but only 10% gave that as the primary reason.

As Horrigan points out, sometimes there is bias in the questions being asked in a survey. A survey that has pre-conceived ideas about why folks don't have broadband will miss some of the reasons. Consider a 2017 survey from the California Emerging Technology Fund. This survey showed different reasons than Pew for why homes don't have broadband because the survey asked different questions. The survey showed:

- 69% said the cost of monthly access and of affording a computer or smartphone was too high. 34% listed this as the primary reason for not having broadband.
- 44% said it was too difficult to set up a computer and to learn how to use broadband, which 12% gave this as the primary reason.
- 42% said they were concerned about privacy and computer viruses, while 21% gave this as the primary reason for not having broadband.
- 41% said they had a lack of interest in being online, with 22% giving this as the primary reason for not having broadband.

The results of those two surveys are drastically different because the surveys asked different questions. If a survey doesn't provide the option to say that privacy is a reason for not having broadband, then that gets missed. People can only respond to the questions asked in a survey as presented to them. For example, there were 12% of respondents in the second survey above that worried about privacy as their primary reason for not having broadband. There had to be people that felt the same way in the Pew survey, but since that question was never asked, respondents were forced to pick from among the choices they were given.

There are numerous ways to compare the availability of broadband in the town to the rest of the state, country, and world.

FCC Adoption Rate

In the 2019 annual report to Congress the FCC reported on broadband adoption by various speeds by state. Adoption rate is the percentage of households that have purchased broadband that meets or exceeds various speed thresholds. For some reason that they don't explain well, in the 2019 broadband report to Congress the FCC reported broadband adoption rates for 2017. This means two things. The overall adoption rates are understated because we know that the overall number of homes buying broadband has been increasing every year. However, since the data used in the FCC report comes from the Form 477 data, the percentage that that buying a given speed is likely overexaggerated. That makes for some confusing results, but since the same issues affect every state, the overall rankings of broadband adoption by state is probably reasonable.

In the 2019 report to Congress, the FCC reported the following broadband adoption rates for Massachusetts (meaning the percentage of customers who are buying the listed speeds at their home):

Homes buying at least 10/1 Mbps	84.3%
Homes buying at least 25/3 Mbps	81.6%
Homes buying at least 50/5 Mbps	70.8%
Homes buying at least 100/10 Mbps	33.3%
Homes buying at least 250/25 Mbps	2.1%

To put the FCC numbers into perspective, the percentage of homes that get at least 10/1 Mbps broadband (84.3%) ranks Massachusetts as having the third highest adoption rate after New Jersey and Delaware.

FCC Availability of Broadband

The FCC also looks at the availability of broadband by county, meaning the percentage of homes that could buy broadband at various speeds. Here's what the FCC reported to Congress in 2019:

Barnstable County

Urban population:	197,419
% that can buy at least 25/3 broadband	98.6%
% with 4G LTE coverage	100.0%
% with both	98.6%
Rural population:	16,025
% that can buy at least 25/3 broadband	98.7%
% with 4G LTE coverage	100.0%
% with both	98.7%

All of the counties in the state except Dukes and Hampshire have similar percentages according to the FCC. It's likely that the FCC numbers are overstated. The way the collect data probably would not have identified the pockets of homes in Falmouth where Verizon is the only option.

How Does the US Rank with the Rest of the World?

Cable Company from the United Kingdom has been gathering data each year that compares broadband speeds and prices from around the world.

The most recent report on broadband speeds is from 2019.[7] The rankings are based upon many millions of speed tests, and 2019 average download speed for the US is based upon over 132 million speed tests. The US ranked 15th in the world in 2019 with a national average download speed of 32.89 Mbps. We are behind countries like Taiwan, Singapore, Sweden, Denmark, Japan, Netherlands, Spain, Norway,

[7] Broadband speeds around the world. https://www.cable.co.uk/broadband/speed/worldwide-speed-league/

Belgium, and others. The average speeds in the US have been increasing and was 25.86 Mbps in 2018 and 20.00 Mbps in 2017. During that time, the US climbed from 21st fastest to the current rank of 15th. The speed increases are largely due to upgrades in speeds in urban areas by cable companies, although there are also fiber-to-the-home builds in both urban and rural markets across the country.

The Gap in Broadband Affordability

The FCC reports that broadband adoption for the country is around 86%. Even after accounting for the rural areas that have no broadband option, there are many millions of customers that can get broadband at their homes, but that do not buy it. Numerous studies and surveys have asked people why they don't buy broadband when it's available. The number one reason that's always cited is price – people say they can't afford broadband.

Statistics on Affordability

In larger cities it's somewhat easy to equate broadband penetration rates to household incomes. This is due to the fact that a Census block in a city might be as small as a block or two, and it's easy to match Census data to broadband data from the FCC.

An analysis of recent FCC 477 data shows that there is a direct correlation between household income and buying a home broadband connection. Only about half (53%) of households with annual incomes under $30,000 buy broadband. This contrasts sharply with 93% of homes with incomes over $75,000 buy broadband. There is no clearer evidence that there is an affordability gap for broadband.

There are studies available for those who want to dig deeper into quantitative and qualitative research into broadband affordability for low income households. The first was published by the Benton Foundation and authored by Dr. Colin Rhinesmith.[8] The second report is issued by the Quello Center and is authored by Bianca Reisdorf.[9] This report looks at a study conducted in three low-income neighborhoods of Detroit.

Both reports say that low-income households with a limited budget appreciate the advantage of having broadband at home but can't fit it into their budgets. They find it difficult or impossible to prioritize broadband compared to paying rent or buying food. These studies indicate that a big part of the solution for getting broadband into homes without it is going to have to involve finding a way to pay for the monthly broadband access.

It's not easy to measure the affordability gap in Falmouth (or anywhere). Every community has low-income homes and senior on fixed incomes where affording broadband is out of reach. We know from talking to the libraries in Falmouth that there are residents who use the public computers since they can't afford broadband at home. Probably the best way to quantify the issue in Falmouth would be to ask the libraries to give a short survey to people who use the library's broadband. Affordability is not the only reason why people don't have home broadband. Later in the report we discuss ways to address the affordability gap.

[8] Digital Inclusion and Meaningful Broadband Initiatives. https://www.benton.org/publications/digital-inclusion-and-meaningful-broadband-adoption-initiatives

[9] Broadband to the Neighborhood. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3103457

Comparing US Broadband Prices to the World

Cable Company of the United Kingdom also tracks broadband prices around the world. The most recent comparison of prices is from 2020.[10] The average price of broadband in the US in 2020 is $50. It's worth noting that these prices were gathered from advertised prices, and most big ISPs in the country advertise special prices that expire after a one or two-year period. The price also doesn't include the cost of a modem or WiFi router. The average price of the US ranks as the 119th most affordable out of 206 countries. However, it's worth noting that most of the countries that are more expensive than the US are either third world countries or island nations. The few exceptions of first world countries that are more expensive than the US are New Zealand, Norway, and Switzerland.

In that same report, the US looks better when looking at advertised prices compared to advertised bandwidth. In that comparison the average cost per megabit of speed in the US is $0.26, placing the US 27th in terms of affordability. However, we know that many ISPs advertise speeds that are faster than what they actually deliver – but this may be true in other countries as well. We also know that many ISPs in the US charge prices t many customers that are higher than advertised prices. The real price of broadband in the US is higher than is shown in this analysis.

ISPs Bridging the Price Gap

Comcast Internet Essentials

Comcast has a low-income program called Internet Essentials that provides broadband to qualifying households. Comcast delivers 10 Mbps download speeds for $9.95 per month. The program was created as a condition by the FCC for its purchase of NBC Universal in 2011. For a long time, the program was lowkey and the company barely advertised it to customers. But over the years the company has embraced the program and in August 2019 announced that it had connected over 8 million people to the Internet with the program (not sure how that translates into households).

In addition to the low monthly broadband rate, those in the plan are eligible to buy a low-cost computer for $149.99. Comcast also offers broadband training in Internet basics, on online safety and security, on using basic computer tools and programs, etc. These training courses are available online or can be taken in person.

Comcast has widened the eligibility for the program over the years, and currently families participating in Medicaid; live in public housing; who participate in SNAP, TANF, SSI, National School Program, Headstart, LIHEASP, or WIC; are attending college under a Pell grant; receive a VA pension; or receive various kinds of tribal assistance.

Verizon

Verizon participates in the FCC's Federal Lifeline plan that is funded from the Universal Service Fund. The plan can provide a discount to low income households for either broadband or telephone service.

[10] Broadband prices around the world. https://www.cable.co.uk/broadband/pricing/worldwide-comparison/

Verizon only makes this available to FiOS customers, so this plan is not available to anybody in Falmouth.

The Homework Gap

In 2010 the FCC adopted the National Broadband plan, and one of the key provisions of that plan is that every American community should have gigabit broadband connections to public schools.

Since that time, the State Educational Technology Directors Association has increased that recommendation and recommend that large schools provide at least 1.4 Mbps of broadband per student for large schools and 2.8 Mbps per student in smaller schools in order to provide adequate bandwidth.

At the end of 2019, only 25 of 1,464 public schools in Massachusetts still don't have at least a 100 Mbps broadband connection (10% of the national goal). The group Education Superhighway[11] reported recently that most schools in Massachusetts have fiber connectivity. The schools in Falmouth are connected to gigabit fiber by OpenCape.

The bigger issue concerning education in the counties is what is being labeled nationally as the homework gap. This is the situation where students have broadband at school but don't have adequate broadband and/or computers at home to enable them to do homework.

The issue recently became a lot more serious when students were sent home due to COVID-19 and asked to finish the school year remotely. The Falmouth School District told us that they only needed to provide twenty cellular hotspots for students that didn't have home broadband. The schools also provided Chromebooks to students without home computers.

How much bandwidth is needed to do schoolwork at home? It varies according the specific set-up at a given school. The typical way for a student to connect to a school system network is through the creation of a virtual private network (VPN) connection. A VPN works by grabbing and reserving a dedicated data path between the home and a server, in this case a school server. While that student is connected to the school, that data path is dedicated to the student and can't be used for other purposes in the home without kicking the student off the VPN connection.

The VPN generally tries to establish both a download and an upload data path. The download path is used to download documents like homework assignments, with the biggest download being when the school homework involves viewing videos that are streaming from the school server. On the upload path the VPN is used when students send completed homework or else perform functions online line like taking a test. The biggest use of the upload connection comes if the students wants to connect with a video connection so that the teacher can see students and vice versa. A 2-way video connection uses both upload and download bandwidth simultaneously.

A downloaded video might use from 1 to 3 Mbps depending upon the amount of action in the idea. The upload stream for video conferencing will require at least 1 Mbps, sometimes a little more. These same

[11] https://www.educationsuperhighway.org/

VPN connections are carved out of the broadband path for each student trying to work from home at the same time along with any adult trying to connect to a server when working remotely.

The Quello Study

Teachers have understood for many years that students without broadband and/or computers at home don't perform as well in class. There was recently a definitive study that quantified the impact of the homework gap. The study was just released in March 2020 and was done by the Quello Center that is part of the Department of Media and Information at Michigan State University.[12]

I call this a definite study because it used study techniques that isolate the impact of broadband from other factors such as sex, race, and family incomes. The study involved 3,258 students in Michigan in grades 8 – 11 from schools described as being in rural areas. The study was done in such a way to get results of schoolwork concerning students without violating student confidentiality.

The study showed significant performance differences for students with and without home broadband. Students with no Internet access at home tested lower on a range of metrics including digital skills, homework completion and grade point average. Some of the specific findings include

- Students with home Internet access had an overall grade point average of 3.18 while students with no Internet access at home had a GPA of 2.81.
- During the study, 64% of students with no home Internet access sometimes left homework undone compared to only 17% of students with a high-speed connection at home.
- Students without home Internet access spend an average of 30 minutes longer doing homework each evening.
- The study showed that students with no Internet at home often had no alternative access to broadband, such as a library. 35% of students with no broadband also didn't have a computer at home. 34% of students had no access to alternate sources of broadband such as a library, church, community center, or homes of a neighbor or relative.

One of the most important findings was that there is a huge gap in digital skills for students without home broadband. To quote the study, "*The gap in digital skills between students with no home access or cell phone only and those with fast or slow home Internet access is equivalent to the gap in digital skills between 8th and 11th grade students*." Digital skills not only require competence in working with technology, but also means the ability to work efficiently, to communicate effectively with others, and managing and evaluation information. This is a devastating finding that students without home broadband fall three grades behind other students in terms of developing digital skills.

Students with lower digital skills translates directly to performance on standardized tests. A student who is even modestly below average in digital skills (one standard deviation below the mean) tends to rank nearly 7 percentiles lower on their total SAT/PSAT score, 5 percentiles lower in math, and 8 percentiles lower in evidence-based reading and writing.

The study also showed lower expectations for students without broadband at home. For example, 65% of students with fast broadband have plans to pursue post-secondary education. Only 47% of students

[12] http://quello.msu.edu/wp-content/uploads/2020/03/Broadband_Gap_Quello_Report_MSU.pdf

with no Internet access have such plans. Students who are even moderately lower in digital skills also are 19% less likely to consider a STEM-related career (that's science, technology, engineering, and math).

Another major study by the National Center for Education Statistics (NCES),[13] an agency within the US Department of Education looked at the homework gap. That study compared test scores for 8th grade students both with and without a home computer. The results showed:

- On tests of reading comprehension, students who have a computer at home had an average score of 268 compared to a score of 247 for students without a computer.
- In testing for mathematics, students with a computer at home scored 285, while those without scored 262.
- In testing science, students with a computer scored 156 compared to 136 for students without a computer.
- In testing competency in information and communication technology, students with a home computer scores 152, compared to 128 for students without a home computer.

Falmouth schools have temporarily solved this problem during the pandemic by providing WiFi hotspots and Chromebooks to students without home broadband connections or computers. The schools told us that they didn't think this was a huge problem and that they gave out 'surprisingly few' hotspots and computers during the pandemic. The Quello study's conclusion that there is a huge lag in academic achievement for students without home computers. This hopefully will prompt the schools and the community to continue to solve the after the end of the pandemic.

Other Uses of Broadband for Education.

The US Bureau of Labor Statistics reported earlier this year that the average American baby boomer held 12.3 different jobs between the ages of 18 and 52 - that was 12.5 jobs for men and 12.1 jobs for women. It's much harder to measure a change in careers, meaning a change to doing something drastically different than prior jobs, but researchers have looked at the data and said that most people change careers at least several times during their work life. The above statistics don't tell the whole story because many people are now working well past 65 years of age, including many older workers trying a new career at the end of their working life.

Many new jobs and careers today require online training. New employees are often expected to complete online training courses at the start of a new job. Many out-of-work adults pursue online training to learn a new career. Anecdotal evidence suggests that taking training or educational courses from a distance (across the country) requires more bandwidth since it's harder to hold a VPN session when the bandwidth varies.

The biggest group of online learners (outside of the COVID-19 crisis) are students pursuing a post-secondary education online. There are almost 20 million college and graduate students across the country, most of which have been recently been notified that most or all of the fall semester this year will be done online.

[13] https://nces.ed.gov/pubs2017/2017098/index.asp

Secondary education has already been in the process of migrating online. Eduventures estimated that the percentage of students already tackling an online degree before the pandemic was 29% of those pursuing an associate's degree, 42% for a bachelor's degree, 27% for a master's degree, and 3% of those working towards a doctorate. In the fall of 2020, nearly all secondary students will have some or all of the curriculum online.

The Computer Gap

One of the things that digital inclusion advocates have learned is that it's not enough to get affordable broadband to a home if they can't afford a computer or other devices to use the broadband. It's also now clear that cellphones are good tools for things like shopping online, but they are inadequate for students trying to do homework. Any plan to close the digital divide has to find solutions for closing the computer gap.

A survey by Pew Research Center in 2019 shows a huge disparity between income and technology adoption. Consider the following results of that poll:

	Less than $30,000	$30,000 to $100,000	Over $100,000
Home Broadband	56%	81%	94%
Smartphone	71%	85%	97%
Desktop	54%	83%	94%
Tablet	36%	55%	70%
All the Above	18%	39%	64%

Other studies have shown that the percentages of homes that have any these technology tools shrinks significantly for homes making under $25,000 per year.

A big problem for low-income homes is that they can't afford both broadband and the cost of buying and maintaining a computer or similar device. Computers are some of the shortest-lived electronics we can buy and typically have to be replaced every 3 or 4 years.

The above numbers highlight the problem of getting broadband into low-income homes – a solution is needed for both broadband and for a computer. As will be discussed below, low-income homes also often need computer training.

The historical solution to lack of computers was to put computers in libraries and public places. However, numerous studies have shown that computers in the home are better than computers in libraries and have a huge positive impact on students compared to any other alternative. Computers have the biggest positive impact on students when they are part of daily life and convenient to use when needed.

We can't forget that computers aren't only for students. Adults need computers today just to participate in the modern world. Computers are needed to hunt for a job. Computers are needed to pursue online training and education. Computers are needed to consider jobs that all employees to work from home. Computers are needed today to interface with many government programs.

There are a number of different approaches that communities have tried to solve the computer gap that will be discussed below in the section talking about solutions for the digital divide.

There is no easy way to quantify the number of homes in Falmouth that don't have a computer. For example, a home might buy broadband to watch Netflix and otherwise only use a cellphone connected to the broadband. We did learn from the schools that they didn't have to hand out very many computers to students during the pandemic.

The Digital Literacy Gap

The current US job market appears to be robust due to the low unemployment rate, which is low by historic standards. However, a closer look at the statistics tell a different story.

Workers with upper income jobs are faring extremely well. For example, starting jobs for new computer, engineering, and similar tech graduates are at an all-time high. It's a good time to be a high-tech worker. However, over half of all job openings in the country are classified as middle-skill jobs (with the three categories being high-skilled jobs, middle-skill jobs, and unskilled jobs). These jobs generally don't require a college degree. An analysis by the Benton Foundation a few years ago showed that over 80% of middle-skill jobs require some degree of digital literacy. Unfortunately, a lot of people seeking middle-skill jobs lack the digital skills needed to land these jobs.

This lack of sufficient digital literacy to find middle-skill jobs is perhaps the best way to describe the broadband skills gap. These are not jobs that need coders, but rather than need people to know basic computer skills like knowing how to use Microsoft Word or Excel. It means being able to type fast enough to do data entry, write-emails, or other expected tasks in the average workplace.

In the early days of the computer age the federal government operated many training programs that taught the basic computer skills. Today it seems to be assumed that students graduate from high school with these skills. However, a student who has never had a home broadband connection or a computer and who only did homework on a cellphone probably doesn't have the needed digital skills. Since the federal and most state governments don't offer any significant training programs in computer literacy, it's up to local communities to find their own solutions.

An example of a non-profit that has tackled this issue is the Enterprise Center in Chattanooga Tennessee. This is a non-profit that is looking for ways to solve the digital divide in the city. Chattanooga is a city that has invested in broadband and offers gigabit broadband on fiber to every resident of the city. However, like in all cities, they found out that low income homes couldn't afford the broadband, didn't have computers, and didn't have the digital skills needed to use a computer. The Enterprise Center began offering basic computer training a year ago and was overwhelmed by the huge number of people who wanted basic training. The Enterprise Center is now looking for ways to greatly expand the training to meet the demand.

Of course, not everybody agrees with that conclusion and there are a lot of people working on digital inclusion who say that the issue is a lot simpler – policymakers don't understand the struggle low-income homes have deciding between broadband bills and food bills.

A Pew Research Center survey in 2016 showed that a lot of adults were interested in digital training. 60% of adults were interested in learning how to use online resources to find trustworthy information. In today's world of misinformation, I would think that percentage is even higher today. 54% of adults were interesting in training that make them more confident in using computers and the Internet.

This is the hardest gap of all to identify because many adults don't want to admit that they don't know how to use a computer. Falmouth already tackles this issue to some extent through programs at the libraries. We've learned from other communities that offer training that they are always surprised at the number of residents who ask for training if it's available.

Future Broadband Gaps

The Future of Broadband Speeds and Capacity

This gap analysis so far has discussed existing broadband gaps. It's important to realize that there will be new broadband gaps coming in the future that we can already predict. One of the issues to consider when looking forward is that broadband speeds are a moving target – that is, the demand for residential and business bandwidth grows every year. This is not a new phenomenon and the need for bandwidth has been growing at nearly the same rate since the early 1980s. Home and business need for bandwidth has been doubling every three to four years since then.

As an example, 1 Mbps DSL felt really fast in the late 1990s when it was introduced as an upgrade from dial-up Internet. The first 1 Mbps DSL connection was nearly twenty times faster than dial-up, and many people thought that speed would be adequate for many years. However, over time, households needed more speed and the 1 Mbps connections started to feel too slow and ISPs introduced faster generations of DSL and cable modems that delivered speeds like 6 Mbps, 10 Mbps, and 15 Mbps. Cable modem speeds continued to grow in capacity and eventually surpassed DSL, and in most cities the cable companies have captured the lion's share of the market by offering internet speeds starting between 100 Mbps and 200 Mbps.

Bandwidth requirements are continuing to grow. Firms like Cisco and Opensignal track speeds achieved by large numbers of households by examining Internet traffic that passes through the major Internet POPs. Both companies estimate that home internet need for bandwidth downloading as well as the need for broadband speeds are growing currently at about 21% annually. Business use of bandwidth is currently growing at 23% annually.

This report earlier discussed how the FCC set the definition of bandwidth in 2015 at 25/3 Mbps. If you accept that speed as an adequate definition of bandwidth in 2015, then growing the requirements for speed every year by 21% would result in the following speed requirements by year.

Download Speeds in Megabits / Second

2015	2016	2017	2018	2019	2020
25	30	37	44	54	65

This is somewhat arbitrary because it assumes that the broadband needs in 2015 were exactly 25 Mbps. For example, if the actual broadband need for the average household in 2015 was 22 Mbps, then the

predicted speed for 2020 would be 57 Mbps. What is not arbitrary is that the need for bandwidth and speed increases over time.

If we accept the premise that 25 Mbps was the right definition of broadband in 2015, then it's reasonable to believe that the definition of broadband today ought to be at least 50-60 Mbps. That would infer that there is a broadband gap today for any customer who can't buy 50-60 Mbps broadband.

Broadband is not only measured by speed and there are firms that track the volume of data that households and businesses use. The firm OpenVault measures total usage by households using software deployed by the biggest ISPs around the country and around the world. They recently announced that the average US household in in the fourth quarter of 2019 used 344 gigabytes of data per month (downloads and uploads combined). That number leaped from 275 gigabytes in 2018 and 215 gigabytes in 2017. Further, OpenVault says that the average cord-cutting household now uses over 520 gigabytes per month – a number that would have floored any network engineer a decade ago.

As might be expected, home broadband usage has exploded to COVID-19. OpenVault reported that as of the end of March 2020 that the average US home used 402.5 gigabytes of usage, up 17% from the 344.0 gigabytes reported just 3 months earlier at the end of 2019, and up 47% from the 274 gigabytes measured a year earlier. OpenVault says that most of the growth was realized in the last two weeks of March as employees and students started working from home in earnest.

One of the most startling numbers to come from OpenVault is what they call power users – homes that are using more than 1 terabyte of data per month. At the end of March, 10% of all US homes were using a terabyte of data, an increase of 138% over the 4.2% of homes that used a terabyte of data just three months earlier at the end of 2019. Even more interesting, 1.2% of homes used 2 terabytes of data at the end up march, up 215% from the end of December. The big ISPs like Comcast are supposedly not billing for data caps during the pandemic – but they must be licking their chops at the flood of new revenues this is going to create if broadband usage doesn't return to pre-COVID levels.

We saw the demand for faster broadband products also leap upward. At the end of March, the percentage of homes subscribing to gigabit data products jumped to 3.75% of homes, up from 2.8% at the end of 2019 and up from 1.9% a year earlier. Amazingly, more than 1% of all homes in the US upgraded to a gigabit data plan in just the last three months – that's something that's been predicted for years. Those homes are not likely going to downgrade to slower speeds – so gigabit broadband is now becoming a significant segment of the market. OpenVault says that 12% of US homes now subscribe to speeds of 200 Mbps or faster.

The OpenVault data also validates what's been reported widely by ISPs – that the pattern of broadband usage is changing by time of day. In the recent past the peak period for broadband usage – the busy hour – was always in the evenings. In the first quarter the amount of usage in the evenings was flat and all of the increased usage came during the daytime as employees and students used broadband and video conferences to function.

OpenVault says that usage peaked in the third week of March. It will be interesting going forward to see the how home usage changes. OpenVault doesn't have any better crystal ball than the rest of us, but they are predicting that broadband usage will never return to the historic patterns. They predict that a lot of people will continue to work from home, meaning increased broadband demand during the day. They

believe there will be continued pressure on the upload data paths. People who have learned to videoconference during the recent months are likely to continue that practice in the future. Companies and employees that realize they can be productive at home are likely to work more from home, even if only on a part-time basis.

These various statistics are a clear indication that the FCC should be periodically increasing the definition of broadband. The agency looked at broadband speeds in a docket in 2018 and concluded that they were going to keep the definition at 25/3 Mbps. However, there was a lot of compelling filings in that docket that argued that the definition of broadband should be 50 Mbps to 100 Mbps.

The point of this section of the report is that we can't get hung-up on the FCC's definition of broadband when looking at the broadband gap. Practically every home that uses broadband would acknowledge that they download and upload a lot more data today than they did just a few years ago.

It's also important to look towards the future when considering broadband needs for the town. For example, if an ISP builds a new broadband solution today, that solution should be prepared to handle the broadband requirements a decade from now. Consider the following chart that predicts broadband needs moving forward. This applies the same 21% annual growth rate for bandwidth demand that we're currently seeing. Forward predictions are always criticized for being too aggressive, but when considering that the need for broadband has been growing at roughly the same rate since 1980, it's not a big stretch to predict broadband needs into the future.

Download Speeds in Megabits / Second

2020	2021	2022	2023	2024	2025	2026	2027
65	79	95	115	139	169	204	247

The download speeds in this table get really large if extended even further into the future. If the demand for broadband download speed continues to grow at 21% annually, then the need in 2030 would be 438 Mbps, in 2035 would be 1.1 Gbps, and in 2040 would be 2.9 Gbps. It's easy to say that such future speeds are not possible, but recall that just 20 years ago, a 1 Mbps DSL connection was considered a blazingly fast broadband connection. A fiber network will be able to keep up with this kind of future demand. There is already fiber gear today that can deliver 10 Gbps broadband to residential customers.

It's possible that the cable company networks could also keep up with this demand, but it would require several major upgrades in technology to do so. Comcast's network in Falmouth can deliver download speeds up to a gigabit today. However, the secret Comcast doesn't want to talk about is that they can't give that much speed to everybody unless they build a lot more fiber and further reduce node sizes. Comcast also would need to upgrade to DOCSIS 4.0 to get speeds faster than 1 gigabit.

It's not hard to put this prediction into perspective. Cable companies that serve over 60% of all broadband customers in the country already provide minimum speeds today of between 100 Mbps and 200 Mbps. That speed varies a bit by market due to the condition of local coaxial networks. But in markets where the coaxial cable in in good condition, big ISPs like Comcast and Charter provide 200 Mbps broadband today as the target speed for their introductory broadband product.

The above chart suggests that by 2027 (or some year close to then) that the Comcast 200 Mbps product will start to feel sluggish to many households. Comcast has unilaterally increased speeds over the years

and it would not be surprising to see them increase the basic speed again before 2027. The company seems to have a policy to stay in front of the demand curve. I'm sure this greatly cuts down on complaints and customer service issues. If the cable companies are staying ahead of this curve voluntarily, it raises the question of why the FCC isn't keeping up with the events in the marketplace.

It's not hard to imagine that seven years from now that the national definition of broadband ought to be around 250 Mbps. That doesn't mean that the FCC will continue to increase the regulatory definition. Last year they rejected numerous filing asking them to increase the 25/3 Mbps definition. There is a political downside if the FCC increases the definition of broadband – it would reclassify numerous homes as not having broadband. Today the 25/3 Mbps definition of broadband is lower than the reality of what many homes need, but my guess is that there will have to a big difference before an FCC will react and change the definition.

One of the conclusions that can be reached by this analysis is that any new network built today ought to be capable of meeting the expected broadband speeds of the next decade. The only technologies capable of meeting the projected future needs for bandwidth are fiber-to-the-premise, cable company hybrid-fiber networks, and some wireless technologies using millimeter wave spectrum that are just now being trialed in a few markets.

Cable companies are only going to able to provide speeds above 1 gigabit by implementing another round of expensive upgrades. There is a lot of speculation in the industry that cable companies would upgrade to fiber-to-the-home rather than make such an upgrade. Unfortunately, if Comcast ever decides that fiber is its future, the company is going to upgrade major metropolitan markets long before upgrading secondary markets like the Cape. Just as Verizon refused to bring fiber to the Cape a decade ago, it would not be surprising in the future to see Comcast reach the same conclusion. Realistically, a fiber network is the only solution that is going to bring the bandwidth that Falmouth will need in the future.

The Summer Population

Falmouth has an interesting summer population compared to many other resort areas around the country. A significant proportion of seasonal rentals in Falmouth are for the summer or for nine months. In many resort areas around the country, few tourists stay for more than a week. The nature of the length of stay for tourists in Falmouth is a good indicator that visitors are going to want the same quality of broadband in Falmouth that they have at home.

The FCC data shows that Massachusetts has the third average fastest Internet speeds in the country, and this is largely due to the prevalence of Verizon FiOS broadband service on fiber that is available in the Boston area. FiOS is also widely available in the cities and suburbs of neighboring states. The slowest broadband connection on FiOS is a symmetrical 200 Mbps connection that provides fast download and upload. It's been widely reported that the FiOS network largely delivers the subscribed speeds, while cable company networks often deliver less speed than advertised.

Comcast and a few other big cable companies serve the urban and suburban markets in Massachusetts and nearby states. When CCG has studied urban markets, we often see that cable company networks are of a higher quality than the network in Falmouth and customers get faster speeds. For example, in many urban markets where Comcast competes against FiOS, the basic Comcast's broadband product delivers

200 Mbps download. We also have studied Comcast markets where most homes get the broadband speeds that customers subscribe to. We don't see this in Falmouth. The speeds in Falmouth are slower than speeds in the Boston area. Further, the speed tests show that a significant number of homes in Falmouth are getting speeds much slower than what customers are paying for.

This all means that many visitors to Falmouth come from homes with faster broadband speeds than what they can get in Falmouth. As has been discussed earlier in the report, the amount of broadband used by the average home has been growing explosively. Even before the pandemic the amount of broadband used by homes has been growing more than 20% per year. Many visitors are going to come from a home where they use broadband for everything. They watch lots of video, people work from home, gamers use big bandwidth, and much of what the home does has migrated to the cloud.

While broadband won't matter to every visitor (just as it doesn't matter to every resident), a significant percentage of visitors are going to want the same broadband experience in Falmouth as they have at home, particularly if they are going to stay for a month or longer. We were told anecdotally by a number of people in Falmouth that many visitors view the broadband speeds in the community as sluggish, and we repeatedly heard from residents that the biggest problem with Comcast in Falmouth is inconsistent broadband. People suffer short intermittent broadband outages, or the speeds vary during the day.

Companies all across the company are having serious discussions about not reopening downtown offices at the end of the pandemic. Business are seeing that productivity hasn't waned when employees moved home, and they are questioning the high cost of expensive office space. Even before the pandemic it's likely that many long-term visitors work remotely while in Falmouth. In the future that's might become the norm.

I also live in a tourist community, in Asheville NC, and my town is currently seeing a real estate boom from people fleeing larger cities and moving here. Almost universally these are high-paid professionals who plan to work from here. The press across the country is full of stories of people in major metropolitan areas fleeing to other towns as they realize they no longer have to live in the expensive metropolitan areas.

A Comcast connection in Falmouth is going to be adequate for somebody working from home unless they need a fast upload connection. Households that want to support multiple people working from home are going to find the broadband in Falmouth to be challenging, and inadequate for somebody who comes to Falmouth from a home with faster broadband. Professionals that need big broadband like doctors, engineers, and architects are not going to happy working on a cable company connection if they are used to something faster at home.

One of the more interesting aspects of looking at broadband in Falmouth is that no town on the Cape has great broadband. For whatever reason, Verizon decided decades ago not to bring FiOS to the Cape. The first community on the Cape to get fiber is going to have a big economic advantage for a number of years. If working from home becomes the new norm, then people are going to want to live in places they love – and it's clear that people love the Cape. The first Cape community with fiber broadband is likely to see a real estate boom and also an influx of more high-paid professionals that will work from home. That kind of change will be transformational because it means that restaurants and other seasonal businesses will thrive all year long.

The Consequences of the Broadband Gaps

There was a time when academics theorized about the impacts of poor broadband. We don't need to theorize today because you can go to any community with poor broadband and residents and businesses will fill your ear with stories of the negative consequences of poor broadband.

Impact of Poor Broadband for Residents

Lower Property Values / Working from Home: We now know that housing prices are higher in communities with great broadband options. While everybody in Falmouth has the option to buy broadband from Comcast or Verizon DSL, there are numerous communities in the state that are served by Verizon fiber and the FiOS product.

Realtors have been reporting across the country that broadband is at or near the top of the wish list for most homebuyers today. During the pandemic there has been a lot of value placed on the ability to work from home – and much of that ability comes from fast broadband upload speeds.

The big question that has to be answered for communities like Falmouth is if people will walk away from homes in Boston that have fiber broadband to work in Falmouth with cable broadband? Some will, but there are many who will instead choose another community that is already served by fiber.

According to Bloomberg, before the pandemic about 4% of the full-time workforce, not counting self-employed people, were working from home. Adding in self-employed people means that work-from-home is becoming a sizable segment of the local economy. Your survey showed 13% of residents in the town working from home before the pandemic (5% full time and 8% part time). It's likely that that number further skyrocketed during the pandemic, and it also seems likely that the number won't drop back to the 13% level but will be something higher in the future.

There are a few communities that recognize the economic benefit of having good-paying employees that work from home. For example, there have been several programs to attract people to work from home. One such program was in 2018 where Vermont offered a cash incentive of between $5,000 and $10,000 for families with a home-worker to relocated to the state. The state has an aging population and wanted to attract families with good incomes to help energize the local economy. The state recognized that the long-term local benefits to the state from attracting high-paying jobs is worth a lot more than the cash incentive they are offering.

Since then other communities have tried the same thing. A similar effort was recently announced in Tulsa, Oklahoma, which has been watching its population drop since 2016. In Tulsa, a foundation is fronting the $10,000 payments used to attract home workers to the community. There is a similar program in Topeka, Kansas and in northwest Alabama.

One corollary of broadband enhancing the value of real estate is that

Education: Even before and after the pandemic, schools have been concerned about the ability to assign computer-based homework to homes with inadequate broadband. Most of the homes in Falmouth have adequate download speeds, and when the pandemic hit in the spring the schools only needed to supply about twenty cellular hotspots to ensure that every student had a home broadband connection.

The issue is not just download data speeds, but also the total amount of downloaded data that even elementary school students needs to do homework. We learned during the pandemic that upload speeds might matter more than download speeds. A student working from home needs to establish a solid and reliable upload link to connect to a school server. Most of the broadband connections in Falmouth can likely support one student or one adult working from home but might not support homes where more than one person wants to make these connections at the same time.

We heard from the schools, and also directly from residents that some homes had problems making connections to school and work servers. The problem mostly arose from homes where multiple people tried to connect outside the home at the same time – the upload speed was not sufficient to make multiple connections. We did not hear that homes with a single student were having any problems connection to school.

Medical / Telemedicine: Telemedicine is uses broadband to connect patients to doctors over the Internet. Patients can talk to doctors using a video connection if the home has adequate broadband. Before the pandemic one of the most common uses for telemedicine was allowing patients able to talk to specialists in distant locations. Another common use has been for holding regular non-intrusive visits for things like counseling so that patients can make a scheduled appointment without major disruption to a work schedule.

A growing area of telemedicine is the use of medical telemetry devices, which can monitor patients after they've had medical procedures. For example, Saint Vincent Health System in Erie, Pennsylvania has been using these technologies and has lowered readmission rates of patients after surgery by 44%. CoBank recently sponsored a trial in Georgia for rural diabetes patients and showed a significant improvement for patients who could be monitored daily and who could communicate easily with doctors.

Telemedicine usage soared during the pandemic. In the past months, telemedicine visits have skyrocketed. During March and April of this year, the billings for telemedicine were almost $4 billion, compared to only $60 million for the same two months in 2019. As soon as Medicare and other insurance plans agreed to cover telemedicine, a lot of doctors insisted on remote visits during the first few months of the pandemic. In those early months we didn't know a lot about the virus and doctor offices were exercising extreme caution about seeing patients.

It's going to be interesting to see the level of telemedicine after the end of the pandemic. There was a recent article about the topic in Forbes that postulates that the future of telemedicine will be determined by a combination of the acceptance by doctors and insurance companies. Many doctors have now had a taste of the technology. It seems likely that the telemedicine platforms in place now will get a lot of feedback from doctors and will improve in the next generation of software upgrades.

The recent experience with telemedicine is going to make a lot of doctor's look harder at their broadband provider. Like most of us, a doctor's office likely relied a lot more in the past on download speed rather than upload speed. It's likely that doctor offices making simultaneous telemedicine visits are unhappy with cable modem service. Doctor's will join the chorus of those advocating for faster broadband speeds – particularly upload speeds.

My prediction is that telemedicine visits will not stay at the current high level but will be here to stay. I think when somebody books a visit to a doctor that they'll be given a telemedicine option when the reason for the visit doesn't require a physical examination. The big issue that will continue to arise is the number of homes without adequate bandwidth to hold a telemedicine session. It's worth noting that the Cape has the highest percentage of seniors in the population in Massachusetts. This means that telemedicine is probably of higher importance in Falmouth than elsewhere in the state.

Possible Solutions for the Broadband Gaps

This section of the report looks at some of the solutions that communities are finding in closing some of these different broadband gaps. It would probably require a 1,000-page paper to cover all of the ideas being tried in different communities, so these are a sample of some of the more interesting and effective ideas being tried.

Bridging the Speed Gap

This feasibility study is being conducted in order to find ways to get faster and better broadband in Falmouth. The ways that communities pursue faster broadband networks are pretty much the same everywhere. Getting faster speeds means building new broadband networks built that can provide the speeds needed to bridge the speed gap. Attracting a new broadband network will require one of the following solutions:

Tackle a New Community-based ISP. There are still only about 200 communities that have built and are operating their own municipal ISP, and most of these communities are small. But it's possible to tackle a new ISP owned by the town, owned by the EDIC, owned by a non-profit corporation, or owned by a new cooperative. These options are all discussed in more detail later in this report.

Seek Partnerships with ISPs that Can Bring Solutions. Most communities want to attract an ISP to the community. Ideally an ISP would bring funding and build and operate a new fiber network, but in communities like Falmouth there aren't any obvious ISPs considering that business model.

The alternative is to partner with an ISP. This study provides the basis for opening discussions with ISPs since it quantifies the cost of a network in Falmouth and demonstrates that an ISP can be profitable in the community.

These options are also discussed in more detail later in the report.

Push State Legislators to Put More Money into State Broadband Grants. State broadband grants in Massachusetts have historically been aimed specifically at the western end of the state. There has been legislative efforts to make the funding available for the Cape. The town and others on the Cape need to keep pressuring the government to bring grants to the Cape – even grants for a fraction of the cost of building the project would make a difference in launching a broadband project.

Investigate Other Funding Opportunities. The EDIC found funding to undertake the downtown business fiber build. There are likely to be grants or low-interest loans for economic development purpose that might help to seed to creation of a fiber project. This will likely take creativity and turning over a lot of rocks, but you've already demonstrated that it's possible.

Consider A Town Grant / Loan to Get Started. We see communities that want fiber networks step up with seed funding. For example, in the last year we've seen towns and counties provide grants between $250,000 and $6 million towards finding a better broadband solution.

Push the Incumbents to do Better. This might sound like a lame suggestion, but we've seen cases where this has worked. For example, it might be possible to convince Comcast to bring the network in town up to snuff with the networks in larger markets.

The report discusses in more detail the possibility of luring Verizon to town to build the new FWA product that can deliver speeds up to a gigabit.

Bridging the Availability Gap

There are steps that other communities have undertaken to help close the broadband availability gap.

Lending Mobile Hot Spots. The schools already did this and provided temporary cellular hotspots to students that don't have home broadband. The library already started a pilot program to lend out Chromebooks and hotspots to citizens. You should consider making these programs permanent. There are always going to be students in the community without home broadband, and some homes in the community can't afford broadband.

Making this permanent requires two things. First, the town will have to fund and buy mobile hot spots in the future. You'd also need to partner with one of the big cellular companies to provide free or inexpensive cellular data to power the hot spots. Other communities have been successful in creating such partnerships.

Create More Public Hot Spots. The town offered good public broadband during the pandemic at the libraries. However, the pandemic showed us that this can't be the only solution. The town should consider funding additional public hotspots. This might most easily be done by starting with the many government buildings that have good broadband from OpenCape. Any of those buildings are a good candidate for the creation of an outdoor hotspot. Outdoor hot spots are particularly effective since they can be made available 24/7 and not just at times when the libraries are open.

Reward Businesses for Creating Hot Spots. We've seen communities that reward businesses for creating good public hot spots. The reward can be anything from public recognition and awards to some sort of break on local taxes and fees.

Bridging the Affordability Gap

This is one of the hardest gaps to solve. Broadband is priced too expensively for some homes, and affordability efforts look for ways to bring less expensive broadband to the homes that most need it.

Inform the Public About Available Programs from Incumbents.

Comcast has a decent low-income product that is available to homes that qualify for several federal low-income programs. Regardless of the press releases, Comcast doesn't widely advertise the availability of the lower-price plans and many homes that qualify for the plan doesn't know about them.

The town could undertake an education campaign to notify citizens about these plans. This would mean developing a fully understanding of the details of the plan – who qualifies and what documentation does a home need to enroll. Armed with that knowledge the town could mount an education campaign to get more subsidized broadband into homes that need it.

Find Broadband Solutions for Public Housing.

Falmouth has some affordable low-income housing complexes. Many communities have found ways to bring better broadband to public housing. A common model is to for the community to buy a high-speed connection to the public housing complex and then use WiFi to distribute broadband to individual living units. Such connections often include low-cost or even free connections from local ISPs as a public service.

There is one national non-profit that concentrates on this effort. ConnectHomeUSA[14] has helped communities find broadband solutions for public housing across the country.

Support Local Affordability Efforts.

There are non-profit organizations around the country that are tackling the affordability issue. One of the more ambitious such efforts is being done by Mobile Beacon.[15] This is a non-profit that works nationwide to bring low cost mobile broadband to non-profits organization around the country, and through those local non-profits brings low cost broadband to low-income people.

There are numerous solutions being used by the non-profits working with Mobile Beacon. One common effort was discussed above which is to provide portable WiFi hotspots that are distributed from libraries. Mobile Beacon has also negotiated a deal with Sprint to provide low-cost cellular broadband to students and others that is priced as low as $10 per month for an uncapped cellular broadband connection.

An interesting study[16] was done looking at the impact of bringing broadband to low-income homes for the first time in the Twin Cities in Minnesota through the Mobile Beacon effort.

- 94% of Mobile Beacon subscribers use the internet daily and 82% say they use the internet several hours a day.
- The average home with Mobile Beacon used 41 GB of data per month. Students used an additional 25 GB per month. People looking for jobs used 14 GB more per month.
- The Mobile Beacon broadband had an immediate impact on students. Parents report that students spend an average of more than 4 hours per week doing homework on the Internet.

[14] https://connecthomeusa.org/

[15] https://www.mobilebeacon.org/

[16] Bridging the Gap. https://www.mobilebeacon.org/wp-content/uploads/2017/05/MB_ResearchPaper_FINAL_WEB.pdf

- The new Internet connection allows adults in low-income homes to get training. 32% of adults in the Mobile Beacon program were taking online courses,

Bridging the Computer Gap

Many communities have solved at least some of the computer gap. During the pandemic, the schools sent Chromebooks home for students that didn't have a computer at home. But the studies we've citied in the report show that students without a home computer lag behind other students, so the community might want to look at a more permanent solution. The Falmouth library is also running a trial of allowing patrons to check out a Chromebook.

Take-Home Computers for all School Kids. It's becoming common for many school districts to send a computer home with every student. In some school systems these computers can only be used to connect to the school system network, making them homework-only computers. But other school systems have recognized that these might be the only computer in a home and let students and their family use the computer for other purposes. The biggest problem with school-provided computers are students that don't have a broadband connection at home.

Foster Programs to Get Computers into Homes

In many other communities, non-profits are finding computers for homes that need them. One such program is the non-profit E2D[17] (End the Digital Divide) in Charlotte, North Carolina. The organization refurbishes laptops contributed by businesses in the Charlotte area and gives them to students. The organization has taken a several-prong approach to making this happen:

- They solicit used laptops from businesses in the Charlotte area. Most big businesses replace laptops every few years and most of them have been ending up in the landfill. Now a number of businesses send all of their used laptops to E2D.
- Used laptops need to be refurbished and E2D started several computer labs in area high schools where they hire students at a decent wage to refurbish the computers and install new software. The purpose of these labs is not only to get the laptops ready to distribute, but they are providing technical training for kids that is helping them move on towards college or a technical career.
- Households that get a new computer also get a live tutorial and technical support to best take advantage of the new laptops.
- Finally, the Charlotte area has a lot of homeless families and there are thousands of homeless kids in the area. E2D has partnered with Sprint to provide mobile hot spots and data plans that are providing broadband access to homeless students and others with no broadband.

The whole concept got started in 2012 when 12-year Franny Millen asked her father how kids without computers can keep up with schoolwork. She wanted to know what could be done about the problem and resolved to fix it. Her father, Pat Millen, founded E2D as a result of her challenge.

Another organization that works nationwide to fund computers is Minneapolis-based non-profit PCs for People.[18] They provide PCs to households that need them and work with other entities including Mobile Beacon and E2D.

[17] https://www.e-2-d.org/

[18] https://www.pcsforpeople.org/

Bridging the Broadband Skills Gap

Every community has a lot of adults who are not comfortable in using computers. There are many cities and non-profits that have created programs to help citizens get basic computer literacy training. Some of the ideas that have worked elsewhere include:

Create a Computer Training Location. One of the most effective approaches we've seen is for the local government to provide a space for computer training. This might be a room that includes a number of computers – something many communities call a computer lab. Once such a training located is created, communities have found that it's not difficult to find volunteer trainers to teach computer skills courses. As mentioned above, when Chattanooga started their training program this way they got twice as many requests for training than what they expected.

Allow the Schools to be Used After hours for Training Adults. A number of communities use computer training centers that already exist in schools to hold after-hours training for adults.

Develop Training Course in the Libraries. A number of communities have developed computer training programs through their libraries. The Falmouth libraries works with citizens who need help with computer skills.

II. Engineering Design and Cost

A. The Technologies

The Technologies we Considered

The RFP for the project asked that we consider all possible technologies that might be used to bring better broadband to the town. Following is a discussion of the three technologies we considered. First is fiber technology that brings a fiber to each broadband customer. Second is fiber-to-the-curb that brings fiber deep into neighborhoods but then uses wireless between the street and homes and businesses. Finally, we considered a full wireless solution using point-to-multipoint wireless technology.

Fiber Optics

We considered two different fiber technologies. Active Ethernet technology has been in widespread use for more than 30 years; GPON has been used for over 15 years. These are both mature technologies that are widely used and well understood industry wide.

Gigabit Passive Optical Network (GPON)

This technology was chosen as the primary way to deliver broadband. GPON makes use of optical splitters so that as many as 32 customers can share the same fiber (i.e., light source). If fewer customers are served from the same light source there is more potential bandwidth for each customer.

A GPON network can be designed in numerous configurations, but all designs include the same key elements. All networks start at a network core where the connection is made to the Internet. At this core the ISP generally inserts the signals for the various products being delivered to customers.

From the core there are direct fibers to Optical Line Terminal (OLT), which are the devices that provide the light source for customers. These OLTs can be located in the same location as the fiber core or else can be spread around in neighborhood nodes, generally in huts or large cabinets.

There is one fiber leaving the OLT for each "PON" which is the local network consisting of up to 32 customers. These fibers go to splitter cabinets where each fiber is then "split" into the 32 separate fibers that go to customers. The splitter cabinets can be located at the same location as the OLT electronics, or they can be moved deeper into the network to be closer to customers. The name "passive" for the technology comes from the fact that the splitter site doesn't require electronics or power – the splitting is just what it sounds like – one fiber is spliced and split into 32 individual paths. The paths from the splitter are "home runs" meaning that there is a dedicated fiber between a splitter site and each customer.

One of the biggest benefits of the GPON network is a savings in fibers in the network. Only one fiber is needed to serve an OLT and one fiber goes from the OLT to each splitter. The fiber is only divided into individual customer fibers at the splitters, which can be deep into the network. The GPON technology chosen provides 2.4 Gbps down and 1.2 Gbps upstream from each group of 32 customers.

Another advantage of PON is the number of electronic interfaces is reduced by the split, since one laser at the OLT can communicate with up to 32 customers. Increased bandwidth can be gained by reducing the number of customers on a PON – reducing a PON to 16 customers would double the bandwidth available per customer. Most fiber builders today choose GPON for residential service because it provides acceptable bandwidth and is less expensive than competing technologies.

One consideration when designing PON networks is the optical distance from an OLT port to the customer ONT; the design of the 2.5 GPON network includes allowance for 1.32 split and a distance limitation of 20 km (12.4 miles) design limit. This design was selected based on current vendor optical transmission availability. Due to the limited size and distances within the electric service territory, the number of remote cabinets resulting from detailed engineering will be mostly constrained by cabinet capacity rather than distance.

Future expansion of the network could utilize several technologies such as course wave division multiplexing (CWDM) or dense wave division multiplexing (DWDM) to increase bandwidth without having to remove, rearrange, and/or replace equipment in the network.

The current vendors for PON equipment include Alcatel-Lucent, Adtran, Zhone, Nokia, and Calix. Today passive optical networks use the gigabit passive optical network (GPON) technology primarily, even though more advanced versions do exist and are discussed below.

Advantages.

- Lower Cost (typically 10-20% less than Active E for the core fiber electronics).
- Can support both RF Broadcast TV and digital IPTV.
- More efficient use of bandwidth at the customer premise. A GPON network delivers 2.4 Gbps of data to a small cluster of houses and an individual customer will normally have access to much of this bandwidth for data transmission, thus giving the customer a faster bandwidth experience at the home.
- For the most part the technology can utilize existing home wiring. The PON network is designed to tie into existing telephone and cable wiring as long as they are conveniently located and in good working order.
- Requires no field electronic devices. The key word about a PON network is that it is passive. This means that no power is needed except in those locations, generally at central offices and major hubs or huts, where the provider places electronics.
- Can easily provide traditional T1s for larger business customers using business ONTs.

Disadvantages.

- Customer must be within 12 miles of hub when using 1x32 splitter. This means with large installations that multiple hubs are required.
- More customers potentially are affected by a fiber failure in the field.

Active Ethernet (Active E)

Each network node in the design is capable of offering metro Ethernet services using active Ethernet technology. This technology provides a direct data connection to a single customer.

An Active E network is essentially a fiber "home run" from the Central Office or other node, meaning that one fiber goes from the electronics core directly to the customer. This technology has several advantages and is well-suited for serving large businesses where the customer requires more stringent network uptime and higher bandwidth. An Active E network also can provide symmetrical data capabilities (upstream and downstream data rates are the same) at high data speeds. The downside to Active E is that more fibers are required in the network since fibers are not shared between customers. Electronic costs are generally also higher since there is a dedicated laser at both ends of the connection to every customer. Active E also has higher data capabilities and can inexpensively provide for data rates up to 10 gigabits per second. Faster speeds are possible, but with significantly higher electronics costs. One of the biggest advantages of Active E is that it's easy to change the connection to a single customer as customer requirements change – the laser serving that customer can be changed without affecting any other part of the network.

The primary vendors in the Active E equipment market are Cisco, Calix, Adtran, and Nokia-Alcatel-Lucent. Since PON equipment has won a much greater market share than Active E equipment, this part of the industry has been in a bit of a decline for a few years. Active E is easier to engineer and expand and is useful for customizing solutions for small volume specialized applications.

Advantages.

- Can serve customers up to 36 miles from last active field device.
- Requires less pre-planning and engineering.
- A single point of failure will often affect fewer customers
- Offers true non-blocking 1 Gbps and faster speeds.
- Easily upgradeable to 10 Gbps by switching optics.

Disadvantages.

- Shares data and CATV bandwidth in the same data stream. Today an Active E system can cost-effectively deliver up to 10 gigabits of data to each home, but more typically these networks are designed to deliver 1 gigabit. This is not a shared pipe with neighbors and each customer can get a dedicated gigabit pipe. However, this one data stream must support CATV, data, and voice together. Thus, if a customer is watching multiple HDTV sets, the amount of bandwidth left for data will be something less than a gigabit.
- The technology has a higher operating cost than PON. It takes more power. Maintenance costs are higher since there are twice as many lasers in the network.
- More physical space is required for electronics because there are more fiber terminations onto the electronics. If the electronics are located in the field, the cabinets housing the electronics and fiber terminations can become relatively large. This means most cabinets need to be on private land and not on public rights-of-way.
- Fewer customers served per electronic chassis. Since only one customer can be served per laser then there are fewer customers that can be served from a single card.
- Larger fiber cables are typically used due to the requirement of a single fiber per customer from the ONT to the electronic chassis. The use of larger fiber cable in an aerial application may significantly increases make-ready costs.

Fiber-to-the-Curb

One of the most intriguing technologies to consider is fiber-to-the-curb. Currently, the company pioneering this technology is Verizon. Verizon refers to the technology as fixed wireless access (FWA). The technology consists of building fiber along streets and then beaming broadband wirelessly to customers using millimeter wave spectrum.

Verizon introduced the technology in 2018 and deployed small trials in Houston, Indianapolis, Los Angeles, and Sacramento. In June of 2020 Verizon introduced the second generation of the technology, with the first new market being Detroit.

The first-generation technology required mounting an antenna on the outside of the home to receive the signal. The new technology hangs a receiver on the inside of a window that faces the transmitter on the pole outside the home. Verizon claims the new technology can be self-installed by customers. One of the key requirements for using the technology is that there must be a good line-of-sight between the transmitter on the pole and customer, which means no intervening trees, shrubs, or other impediments.

Verizon claimed that the first-generation equipment technology could deliver speeds up to 300 Mbps for up to 2,000 feet from a pole. Many engineers in the industry guessed that the more realistic distance was 1,000 feet or less. Verizon claims the new technology can deliver speeds up to a gigabit, but Verizon is no longer making any distance claims. The industry consensus is that this new technology also is likely limited to perhaps 1,000 feet from transmitter to customer window. The receiver in the window needs to 'see' the see the transmitter on a pole, so this is a line-of-sight technology where only homes within sight range of a pole can receive the broadband.

Verizon publicly claims that the technology will meet all 5G specifications. However, currently there are no 5G features yet being used in the field, and so the current generation of technology is basically a millimeter wave radio path to a home. When 5G is finally introduced in the field this technology might benefit some if it can use the 5G features that tailor bandwidth paths to customer demand. But since most 5G features are intended to benefit cellular traffic, this specific technology is not likely to improve much even if layering on 5G features.

From a deployment perspective, this is an expensive technology. It requires building fiber deep into residential neighborhoods. The industry analysts at MoffetNathanson looked at the first-generation equipment and said they didn't see how the technology could be any cheaper than building fiber-to-the-home. The expensive part of a FTTH network is the fiber along a street, and that is still needed for this technology as well.

Verizon claims to have plans to pass 30 million residents with the new technology. The pricing on the product is simple, at $50 for Verizon Wireless customers and $70 for anybody else. This technology will compete well against cable since the cable companies currently sell gigabit broadband at prices of $100 or higher. This product should also have faster upload speeds than cable broadband, but Verizon isn't talking yet about upload speeds. Any neighborhood that gets this technology ought to see some price competition – and if not price competition, at least expanded customer choice.

This technology doesn't make sense everywhere. It's a technology aimed at streets with single family homes or rows of small businesses. It's not going to handle apartment buildings where there are units that don't have a street-facing window. The technology doesn't work well in neighborhoods where utilities are buried since this needs to be on poles. This could be placed on light poles, but it's more expensive to get fiber to light poles than it is to utility poles. The technology won't work well on streets with heavy vegetation or streets that are highly curved. This technology will be hard to justify in places with neighborhoods with large lots and lower housing density, and this technology makes no sense in rural areas.

This is a new technology and the only company currently offering it is Verizon. Verizon is currently using a proprietary technology it developed. There are likely to be commercial vendors offering this technology, but that could still be some years away. It's too early to have any customer or industry review to talk about how it really works. However, if it operates anything like how Verizon claims, it could be a serious competitor to cable company broadband.

There are a few clear pros and cons for the technology:

Advantages:

- If speeds are near to a gigabit as claimed by Verizon, this is a robust technology. Basically, the technology replaces a fiber drop with a wireless connection.
- There is a definite savings if customers can self-install the technology, and that lowers customer costs by at least $200 per new customer.
- This eliminates the issue of building fiber drops to customers who then later drop the service and strand the drop investment. Any customer within range of a given transmitter can quickly be added or dropped from the network.

Disadvantages:

- There are going to be homes that can't use the technology. Any home with significant shrubbery or blocking hedges might not have a clear sight of the transmitter on the pole.
- The technology also works best in neighborhoods with straight streets where one transmitter can see multiple homes.
- It's hard to know how this affects long-term operating costs. We know that fiber drops can operate without problem for decades. This technology replaces those drops with pole-mounted wireless transmitters, and those units are going to wear out and have to be replaced. But fiber drops can be stranded for customers that drop the service. We'll have to see over time if this technology is more or less expensive than fiber-to-the-home.
- The technology is not yet available, but it's likely that it will be available eventually.
- Verizon uses licensed spectrum to communicate between street and customer. There are some unlicensed bands of millimeter wave spectrum, but it's too early in the use of that spectrum to know if there will be any interference using unlicensed spectrum.

Point-to-Multipoint Wireless

This technology is widely used in rural America today and it was recently estimated that there are at last six million homes connected to the technology. The technology has been around for almost twenty years, but recent breakthroughs in wireless technology plus an expansion of the spectrum being used has made this a technology to consider.

The wireless network used to deploy the technology typically consists of radios placed on towers or other tall locations and connections to homes and businesses are beamed wireless. There are several current frequencies of spectrum that can be used for this purpose and more that will be coming on the market in the next few years:

- WiFi: WiFi is short for wireless fidelity and is meant to be used generically when referring to any type of 802.11 network. The FCC has currently set aside two swaths of frequency for WiFi: 2.4 GHz and 5.7 GHz. In a point-to-multipoint network, these two frequencies are often used together. The most common way is to use the higher 5.7 GHz to reach the closest customers and save the lower frequency for customers who are farther away.

  In practical use, in wide-open conditions, these frequencies can be used to serve customers up to about 6 miles from a transmitter, although speeds can be slow at the far end of six miles. Nationwide many wireless carriers advertising speeds in the range of 25 Mbps. We know of networks using only WiFi that can deliver up to 50 Mbps for short distances. Such a network must have fiber built to the radio transmitters and can't carry too many customers on a given radio system.

  The FCC has recently approved the use of 6 GHz WiFi spectrum for both for indoor use and for use in outdoor point-to-multipoint networks. This new spectrum should significantly boost the bandwidth that can be delivered to customers. There are around 100,000 existing outdoor microwave links using the frequency and any ISP that uses the spectrum must work around existing deployments.

- CBRS Spectrum - 3.5 GHz: In 2019 the FCC approved the use of the 3.5 GHz spectrum band known as the Citizens Broadband Radio Service or CBRS. This is a huge swath of spectrum covering 150 MHz of spectrum between 3550 and 3700 MHz.

  The FCC has set aside 80 MHz of this spectrum for public use, similar to WiFi, and just concluded an auction for the remaining spectrum of 70 MHz as this report was being written. In all cases this spectrum is shared with military uses and the military will always get priority to use the spectrum.

  The spectrum also must be shared among users in the public space – something that will be monitored by authorized SAS administrators. The FCC named five administrators in the docket: Amdocs, CommScope, Federated Wireless, Google, and Sony. It's expected that the cellular carriers are going to heavily use the public bandwidth for delivering 5G, so in many places this spectrum might be too busy for using in a point-to-point application. However, in some rural markets the public spectrum could go unused, in which case it would be available to boost the speeds for fixed wireless broadband.

  The FCC is also making it a little easier for smaller companies to win some of this spectrum in the coming auction. The spectrum will be auctioned by county, one of the smallest coverage areas ever used by the FCC. There is hope that the bigger carriers won't pursue the licensed spectrum in rural areas since they can use the free spectrum. The FCC has provided bidding credits to smaller entities to help them bid against the larger carriers.

There are already a few rural carriers using the public portions of the spectrum for fixed wireless service. This spectrum sits in the middle between the two WiFi bands used for fixed wireless today and has great operating characteristics.

- White Space Spectrum: The FCC has been doing trials in what is called white space spectrum. This is spectrum that is the same range as TV channels 13 through 51, in four bands of frequencies in the VHF and UHF regions of 54–72 MHz, 76–88 MHz, 174–216 MHz, and 470–698 MHz. The FCC approved greater use of these frequencies for point-to-multipoint radios.

  The FCC auctioned a lot of this frequency in 2018, with the buyers ranging from the big cellular companies to Comcast. This was called an incentive auction, because TV stations that gave up their spectrum for a TV station got a share of the sale proceeds. We've been expecting the FCC to make this spectrum available for point-to-multipoint radios, but that hasn't yet happened.

  There are two possible uses for the spectrum. On a broadcast basis, this can be used to make better hotspots for places like coffeeshops. A 2.4 GHz WiFi signal can deliver just under 100 Mbps out to about 100 meters (300 feet). But it dies quickly after that and there may be only 30 Mbps left at 200 meters and nothing much after that. Whitespace spectrum can deliver just under 50 Mbps out to 600 feet and 25 Mbps out to 1,200 feet.

  There is also potential for the spectrum to extend point-to-multipoint radio systems. White space radios should be able to deliver about 45 Mbps up to about 6 miles from the transmitter.

  One issue to be worked out is that the FCC rules require the radios using this frequency to use what is called cognitive sensing. This means that an unlicensed user of the spectrum will be required to discontinue any requests that interferes with a licensed user. This might make the spectrum hard to use in markets where there is a mix of licensed and unlicensed users.

  C-Band Spectrum. On February 7, 2020, the FCC announced an upcoming auction in December 2020 of C-Band spectrum. This spectrum sits between 3.7 GHz and 4.2 GHz. The spectrum has historically been used by satellite companies for communication between satellites and earth stations. This is prime spectrum for 5G cellular broadband, but also could provide a huge benefit to fixed wireless providers in rural America.

  The FCC is expected to hold an auction for this spectrum in December 2020. FCC Chairman Pai is asking Congress to approve using 10% of the proceeds of the auction to provide the spectrum for rural broadband. At this early stage there's no way to know if Congress will do this or how it might work.

  The C-Band spectrum sits next to the recently released CBRS spectrum at 3.5 GHz. Just as additional spectrum benefits 5G, fixed wireless technology improves significantly by combining multiple bands of frequency. Rural carriers have been arguing for years that the FCC should allow for the sharing of spectrum. Proponents of rural broadband argue that two uses of spectrum can coexist since most 5G spectrum is only going to be needed in urban areas. They believe that such spectrum can be used in a point-to-multipoint configuration without interfering with urban

5G. The big cellular carriers have always been reluctant to share spectrum mostly because it causes them extra effort, so only the FCC, and in this case Congress, can make it happen.

There are several factors that are critical to the success of point-to-multipoint radios for delivering broadband to homes and businesses:

- Using Multiple Frequencies. The newest radios are much improved over radios from just a few years ago because they use spectrum bands including 2.4 GHz, 3.5 GHz, and 5.0 GHz. Radios will get even better if they include white space spectrum, CBRS spectrum, and/or C-Band spectrum. Having more spectrum matters because each frequency band has different operating characteristics in terms of distance and ability to penetrate obstacles. Having multiple frequencies available means an increased opportunity to find a good solution for each customer in the service area.
- Adequate Backhaul. The best fixed wireless coverage comes when there is fiber at the transmitter. Customer broadband speeds are diminished if a tower doesn't receive enough bandwidth.
- Terrain/Topology. There are often physical barriers like hills or heavy woods that can limit or block customer bandwidth. Most of these technologies require a line of sight, meaning that there must be a clear unimpeded visual path between the tower and the customer. Customers that live in valleys or behind hills might not be able to get service. If the signal has to pass through trees or other obstacles the strength of the signal is diminished. In towns, a home might block a neighboring home from receiving the signal. The signal can also degrade with rain or snowstorms blocking some of the signal.

There are a number of downsides for using this technology in town setting, which are described in the following list of advantages and disadvantages.

Advantages:

- It's hard to know if this is an advantage or disadvantage, but the latest technology can deliver up to 100 Mbps broadband to customers that are within a few miles of a tower. In Falmouth that's not as fast as Comcast, but it's a lot faster than Verizon.
- It's likely that speeds will get a little faster, but this is not likely to ever be a technology that will deliver 200 Mbps, due to constraints of physics for the various spectrum bands being used.

Disadvantages:

- The biggest disadvantage is the maximum speed of the technology. In ideal conditions point-to-point wireless can deliver about 100 Mbps broadband. That would not compete well with Comcast, and within a few years will feel slow.
- There is an upward limit on how many customers can be served from a single tower. At best a tower can handle about 600 customers. This means in Falmouth it would take dozens of towers to reach everybody.
- The second big disadvantage is that the fastest speeds can only be delivered for about two miles, with speeds a little less at three miles and much slower after that.
- In a city environment, a configuration of dozens of towers would create interference between towers and would degrade performance for everybody.

- The frequencies most often used are unlicensed, which makes them generally open to interference. Further, some of the newer bands of frequency must defer to coverage by the government, the military, or licensed spectrum holders.

The bottom line is that the technology doesn't fit Falmouth. It might be possible to still incorporate the technology into a larger broadband infrastructure. For example, there might be a few homes in town that are tremendously expensive to reach with fiber and this might be a reasonable alternate. There are also a few ISPs that are using the technology to provide broadband to boats that are within a few miles of shore. From a recreation standpoint that would be a community advantage.

Why We Chose Fiber

After considering the above technologies, we finally chose GPON fiber as the technology that would best fit for bringing broadband to everybody in Falmouth. Following are the primary reasons we chose fiber:

Wireless Technology. The best commercially available wireless technology that could be provided today using unlicensed spectrum can deliver perhaps 100 Mbps download broadband. That's not a bad broadband product today, but it doesn't fit Falmouth for the following reasons:

- This matches the speed of the basic bandwidth product offered by Comcast but cannot be made to deliver faster broadband.
- In a town setting even the 100 Mbps speeds might be troublesome to achieve. The FCC has set aside a lot of free spectrum in rural areas that cannot be used in towns, and without the extra spectrum the speeds would likely be slower.
- At best, the future potential of the technology might eventually be 200 Mbps – so this product is not future-proofed.
- Biggest downside is that perhaps 200 homes can be served from a given transmitter. In a town like Falmouth this means the need for a lot of antennas.
- The technology also requires line of sight between transmitter and customer – it's hard to envision designing a network that could serve everybody because of the topography and the trees in many parts of the town.

Fiber-to-the-Curb. This is the technology that builds fiber on each street but then delivers bandwidth into the homes using wireless technology. We didn't choose this technology for the following reasons:

- Today the only company deploying this technology is Verizon, using proprietary equipment. However, it's likely that some vendor will eventually make this available to everybody else.
- Today this is more costly than building fiber. This requires building fiber everywhere, so that cost is the same. This also involves putting electronics on poles at and at the home to deliver broadband – which is currently a lot more expensive than just putting electronics at the home. But over time this could become cost-justified.
- This requires line-of-sight from street to homes. This means homes with heavy foliage might be hard to serve. You can guarantee bringing fiber to everybody – there will be homes that this technology will not reach.
- This is also a challenge on streets where utilities are buried. The transmitters (and the fiber that fed them) have to somehow be bright to light poles or other structures.

- For now, this technology delivers perhaps half the bandwidth as fiber-to-the-home, but that could get better over time. However, this technology may never take the next leap forward when fiber electronics are upgraded to 10 gigabits to each customer.
- This technology might eventually be a complement to fiber and fiber network owners might use wireless instead of fiber drops in some instances. But that easy interchangeability is probably a decade or more into the future.

So Why Fiber?

- Fiber can deliver a symmetrical gigabit product to every customer in the community today. No other technology today can match that. The network we've designed would also allow large customers to get 10 gigabit or 100 gigabit service today.
- Fiber technology evolves over time and 10 gigabit PON technology is already available. For now, it's a little more costly than 1 gigabit PON, but that price difference should disappear over the next few years. Vendors are already testing 40 gigabit fiber in the lab, which will probably hit the market in a decade. No other technology will ever be capable of the nearly unlimited speeds possible on fiber. Fiber is the gold-standard for being future-proofed.
- PON fiber technology is a mature product and can be operated without taking a technology risk.
- Since fiber is delivered to customers via wire, there are no customers in the town that can't be reached by a fiber network.

B. Network Design

We finally selected fiber-to-the-home as the only reasonably affordable technology that could bring fast broadband to everybody in Falmouth.

Passings

The telecom industry uses the term passing to mean any home or business that is near enough to a network to be considered as a potential customer. We used the town's robust GIS system to identify structures and potential customers. Our engineers settled on the following as the count of potential passings for the study.

Full Time Residences	14,232
Seasonal Residences	7,800
Business Passings	2,000
Total	24,032

The basis for each of these groups of passings is as follows.

- Residential. This includes single family houses, including apartments, condominiums, townhouses, etc. In Falmouth, the vast majority of residential passings are single family homes, although there are some apartments, townhouses, and condominiums.
- Seasonal Homes. The volume of seasonal homes creates a challenge for a broadband business plan. Most seasonal homes don't want to pay for broadband for the whole year.

- Businesses. This represents standalone businesses that could purchase broadband. We have not reduced this count for the businesses that use OpenCape since those businesses might eventually be served by a new fiber network.

Miles of Fiber Construction

Our engineers determined that the needed network requires 460 miles of fiber construction, as follows. There is a map showing the location of aerial and buried fiber construction in Exhibit III.

Aerial Fiber	390
Buried Fiber	70
Total	460

This does not build fiber on every street in the town. We avoided 92 miles of fiber construction that run through undeveloped neighborhoods, that follow utility roads, use bike paths, or for streets where there was a shorter way to reach homes.

Design Considerations

A FTTP network would bring fiber to homes and businesses. There are several key factors to consider in the design of a rural fiber network:

- Whether to use buried fiber, aerial fiber, or some mix of the two.
- The specific electronics design philosophy.
- Redundancy
- Connectivity to outside world

Fiber Design Considerations

Aerial versus Buried Fiber. The first decision that has to be made for building fiber is whether to put the fiber on existing poles or to bury it underground. There are a few key issues that usually drive this decision:

- Cost. If there is a big cost differential between the two construction methods, most fiber overbuilders will choose the lowest cost option, assuming it's a valid option. A general rule of thumb when designing a fiber network is to try to bury fiber where other utilities are buried and to try to construct on poles when other utilities are on poles.
- Maintenance. Aerial fiber is subject to damage from weather. In Falmouth that means the occasional nor'easter and ice storms. The owner of an aerial fiber network must be prepared to make repairs after storms and also face the occasional major outages that follow a bad storm. However, buried fiber is not without issues. The primary cause of outages for buried fiber is fiber cuts due to somebody excavating in the rights-of-way. The primary fiber cuts in towns usually comes from mistakes made by other utilities. There is a process for anybody working underground to locate existing utilities, but invariably other utilities or their subcontractors will shortcut the process to locate the fiber before digging.
- Access. There are circumstances where it's impossible to use one of the construction methods. For example, both municipalities and electric cooperatives are not required, by federal law, to allow fiber builders to use their poles. CCG Consulting is aware of one case in West Virginia

where an electric cooperative did not allow a competitive fiber builder to use their poles. Private landowners are not required to grant rights-of-way for fiber. This means owners of private roads can block aerial or buried fiber. Since most places want fiber, we don't see fiber kept out of many neighborhoods – but we have seen private subdivisions prohibit fiber if it means digging up their private streets.

- Impediments. There are special circumstances that can make it more expensive and time-consuming to build fiber. For example, it's often expensive and time-consuming to gain the needed rights-of-way to build fiber across bridges, under railroad tracks, or under freeway overpasses. There are often complicated rules that must be followed to build fiber through state and national parks and forests. We know of states where the Department of Transportation adds burdensome rules to build along state highways.
- Rights-of-Way. Most public roads already have a defined public right-of-way along the sides of a road. Such areas are usually designated by state laws or local ordinances that specifically define the right-of-way. Utilities are allowed to construct in existing rights-of-way, but only to the extent that they do so without harming existing utility infrastructure. Rights-of-way become an issue when building on private lands or roads.

Considerations for Burying Fiber. Buried fiber is constructed using several different methods. These are described in more detail later in this section of the report.

- Trenching. With trenching, a trench is excavated alongside of the road and hardened fiber is either laid into the trench or else conduit is placed in the trench and then fiber is pulled through.
- Direct Buried / Plowing. In places where the soil is soft and there are few rocks it's possible to use a heavy vehicle to "plow" fiber or conduit directly into the ground.
- Boring. With boring, a machine bores a horizontal hole through the earth at the suitable depth and a conduit is then pulled through the hole. Fiber is then pulled through the empty conduit.
- Microtrenching. The newest construction technique is microtrenching, where a one inch wide and 8 to 12-inch deep trench is cut into the street pavement.

The soil conditions vary throughout the town, but the soil condition in much of the town are considered to be at least somewhat rocky – a condition that adds to the cost of burying fiber. There may be existing roads where the substrate was excavated during the initial road construction, and in such places, it might be relatively easy to bury fiber. However, any buried construction in some parts of the town is likely to hit some rock – something that can easily quadruple the cost per foot to bury fiber.

Considerations for Aerial Fiber. There are a few issues that affect using aerial fiber, and it's not always the cheapest or easiest alternative.

Make-Ready. The most important aspect is something that the industry calls make-ready. There are national electric codes that define the spacing between the wires of different utilities. In rural areas most poles will already be carrying electric wires and telephone wires. There also could be existing fiber on some roads that is used for some purpose other than serving households and businesses.

The national electric codes include two important requirements that can affect the cost of getting onto poles. There must be sufficient space between the different providers on a pole. For example, a new fiber must be at least 18 inches above the cable below it (be that a telephone cable or wires from a cable TV company). There are also minimum clearance rules for the lowest

that any cable can be above ground for the safety of those beneath the pole. These rules are in place to provide safety for technicians that work on cables during and after storm damage.

When there is not sufficient room for a new wire, then an industry practice called make-ready is invoked. Make-ready is the process of moving the existing wires on poles, as needed, to make room for a new wire. The make-ready can be somewhat simple, such as moving an existing wire by a few inches, or it can be major, such as having to move all of the wires on a pole or possibly even replacing the pole with a taller one.

Make-ready is expensive for two reasons. First, the new attacher has to pay to make all of the needed changes, even if the old wires were out of specification. Second, there can be big time delays while other providers using a pole make their changes to make room. Make-ready can be so expensive that in some cases it's cheaper to bury a fiber rather than to deal with the cost and delays doing the make-ready to be able to add a new fiber.

One Touch Make-Ready. The FCC passed new rules that went into effect in May of 2019 that should make it easier to get onto poles. The new rules apply only in the thirty states that follow FCC pole attachment rules. Massachusetts has asserted jurisdiction over poles and this order doesn't apply. However, almost every state is adopting similar rules, so this is worth discussing.

The most significant change in the rules is a new classification of poles as either simple or complex make-ready. The order defines how to make this classification. In real life practice, the new attacher will suggest this determination, although it could get overturned by the pole owner.

There are new streamlined rules and timelines for completing the make-ready on simple poles. If the pole owner is unwilling to commit to fixing simple poles in the needed time frame, the new attacher is allowed to make the changes after properly notifying the pole owner. The new attacher is free to rearrange any existing wires as needed, again after having properly notified all of the parties. These new rules eliminate situations where a pole owner refuses to cooperate with a new attacher, as happened in a few cities where AT&T fought Google Fiber. Something to consider is that the rules require using a make-ready contractor that has been pre-approved by the pole owner – but there are ways around this in some circumstances.

These new rules can mean a big improvement in construction schedule where the needed changes are for simple poles. That would be poles where wires need to be moved to make room for the new attacher. However, the new rules are not necessarily faster for complex poles. Those are poles where the make-ready could cause damage to existing wires or where the old pole must be replaced. The make-ready process for complex poles has always been slow. The new rules tighten up time frames a little, but the time required to get onto a complex pole can still take a long time.

For complex poles the process will still allow the existing wire owners to work sequentially – meaning that they can invite each existing company on the poles to do their own work, one company at a time. This coordination has to be scheduled by the pole owner. The process could still take six months even if done perfectly. The new rules don't seem to provide a solution for when the pole owner or the existing attachers drag their feet on complex poles. Other than some

slightly improved timelines, the work on complex poles looks to still be as dreadful and slow as the old make-ready rules.

The Components of a Fiber Network

A fiber optic network that is designed to serve large number of customers generally has several major elements:

- Feeder Fiber. This is the fiber that starts at the core of the network and stretches to the various neighborhoods to be served.
- Distribution Fiber. This is the fiber that generally is then build up and down streets to pass each potential residential or business customer.
- Drop Fiber. This is the fiber that is built from the street to reach the premise of each customer served by the network.

Microtrenching

The RFP asked us to specifically address microtrenching. This is a relatively new construction technique that involves digging a narrow trench a few inches wide and a foot or so deep. These trenches can then hold multiple conduits for fiber.

The positives for this technique are significant, mostly dealing with cost. The alternative to microtrenching for traversing sidewalks, driveways and parking lots is boring. The boring technique involves digging a somewhat deep hole of 3 – 5 feet and then using equipment to bore sideways underneath the concrete. There is significant labor involved in the process and there is always a danger of hitting other utilities, particularly when boring away from public rights-of-ways.

But there are significant downsides. Probably the biggest downside is that the trench is a lot shallower than other kinds of underground fiber construction. Microtrenched fiber will be a problem any time a street is being repaved. When it's time to repave a street the typical construction process is to excavate between 18 inches to three feet depending upon local soil and substrate conditions. During a street repaving the fiber will be cut and removed and likely to be unable to be quickly replaced – meaning long outages for customers living along streets undergoing repaving.

Many vendors are recommending microtrenching for crossing big parking lots, campuses, or other private facilities. The question to ask is if it's realistic to think that some portion of the fiber won't be excavated for some unrelated purpose long after nobody remembers exactly where the fiber is at.

The most pressing issue with microtrenching is the likelihood of fiber being cut by other utilities working on problems like gas line or water main repairs. To use the example of my own city of Asheville, North Carolina there is typically a new cut made in the street somewhere in the city every day by crews digging to reach gas or water line problems. If there was microtrenched fiber everywhere in this city, then every cut from other utilities could result in a fiber cut – an outcome that customers would find to be unacceptable and that would result in significant costs for an ISP.

Microtrenching has also gotten a bad name in a few deployments. Google Fiber used microtrenching in Louisville Kentucky after they were unable to get access to poles. Within a year after construction the fiber began popping out of the microtrenches all over the city. Everybody I talked about the issue

blamed this on ice heaving. While a micro-trench is sealed, it's likely moisture somehow got into the microtrenches in Louisville. The first freeze would create tiny cracks, and with each subsequent freeze, the cracks would get a little larger until the trench finally fills up with water, fully freezes and ejects the fill material. The only way to stop this would be to find a permanent seal that never lets in moisture. That sounds like a tall task in markets where there is a daily freeze and thaw during the winter. Google Fiber ended up walking away from the Louisville market after the company had spent millions constructing fiber using microtrenching.

The Louisville deployment was the first time we've heard about microtrenching being deployed on a large scale and it was a disaster within a year. But even had the microtrenches not have failed due to ice heaving, the network was going to have constant outages caused by the street cuts that happen routinely in every city.

There are major metropolitan cities that have considered allowing microtrenching for sidewalks. That avoids the issue of losing fiber when routine cuts are made into street asphalt or when a street is repaved. But sidewalks are also routinely cut, and it would be an ISP nightmare if every sidewalk cut resulted in a fiber cut and outage.

Even if assuming that microtrenching can be done without ice heaving there are two big downsides to microtrenching. The first is routine fiber cuts. A normal buried fiber network in a city might only experience a handful of fiber cuts per year, mostly done by some other utility. If fiber is buried at 3 feet below street level, there aren't a lot of opportunities to cut the fiber. A city with widespread microtrenching might see a fiber cut almost daily as cuts are made in streets to make repairs to other buried utilities. A microtrenched fiber will be only 8-12 inches below the street surface, and so any cuts in the asphalt have a high likelihood of cutting fiber. This means pockets of customer taken completely out of service on a daily basis. In many cases, a cut made for a gas or water problem might stay open for days, or even weeks, and that means prolonged outages for affected customers.

Even worse is the consequences of repaving a street. In that process the street is generally excavated to a dept of 2 – 3 feet and then refilled and repaved. The repaving process could result in a fiber cut that lasts for many weeks.

Cities have standards about burying utilities are various depths for a reason. Deeply buried utilities are rarely disturbed, particularly from routine street cuts that are a part of urban life. Microtrenching falls outside of that norm and microtrenched fibers are highly likely to be routinely cut.

Cost Differential for Aerial, Buried, and Microtrenched Fiber

The biggest cost component of deploying fiber is labor. From a material cost perspective, the costs of materials are similar between aerial and buried construction. Buried construction costs include the cost of conduit, which can be between $1 and $2 per foot of added costs. However, there are also added costs for aerial fiber construction including the cost of pole mounting hardware and the cost extras like shielding against squirrel damage.

Labor costs vary around the country due to differences in hourly wages, but in general the labor cost of the various kinds of construction can be compared on a per foot basis. Following are the different types of fiber construction mostly seen in a market.

Trenching. This is buried construction where a ditch a 12-inch wide ditch is dug in the street or along the side of the road, the fiber is placed in the open ditch, and then the ditch is refilled. This is generally the most expensive type of construction, particularly if ditches have to be dug in city streets – the cost of digging and then replacing asphalt can be costly. Trenching is also disruptive and city streets must be blocked off until a new surface has been poured and cured in the ditch. Trenching is typically used only in situations where other methods of construction won't work. In a typical urban build, you would expect less than 1% of the total construction to involve trenching.

Boring. Boring is the most common method of burying fiber. In boring, a "pothole" is dug in the street, which means a hole approximately 2 feet by 2 feet. A boring machine is inserted into the empty pothole and laterally drills a hole through the substrate of the street. Empty conduit is then pulled through the freshly dug hole. Conduit is flexible and durable plastic tubing. Eventually the fiber building will push or pull fiber through the empty conduit. Boring costs can vary widely depending upon the composition of the substrate. If roads were originally dug out to a three feet depth when constructed, then it's relatively easy to bore through an area. Boring is much harder and expensive, and sometimes impossible in areas where there is native rock close to the surface of the street. There is often an intermediate condition called cobble the substrate under the street includes boulders that were put back into the hole when a street was repaved.

Plowing / Direct Burying. In rural areas where there is an unpaved shoulder along roads, a common construction method is to direct bury the fiber into the ground. This involves using a heaving truck that plows a furrow in the ground, just as would be done by a tractor on a farm. The plow pushes fiber into the ground at the same time that it buries. There is most often not even any follow-up construction since the plowed furrow naturally closes after the plow passes. Direct burying is rarely used in cities, but there might be a few roads in Falmouth, particularly along the ocean where this could be done for short stretches.

Microtrenching. This was described just above in the report and involves digging a 1 inch wide by 8- to 12-inch-deep trench in the street, putting in the fiber, and then refilling and sealing the hole.

Aerial Construction. The typical aerial construction of fiber includes three phases. First is make-ready, where work is done to make the poles ready for construction. This might mean tree trimming. It often involves having to move wires on existing poles to make room for a new fiber. In the worse cases, if poles are too full of wires it means replacing some percentage of the poles with taller poles.

Once the make-ready is done, the most common construction method is to install a "messenger" wire on the poles. This is a sturdy metal wire. Finally, the fiber is lashed onto the messenger wire.

Comparison of Construction Costs.

Again, these costs are illustrative, but come from real life examples. These costs can vary in a given community due to local conditions and can vary locally depending upon local wages. The following figures represent just the labor component of construction. These costs also account for the effort to splice in local access points where customers can be connected to the fiber.

Trenching in city streets	$50 - $60 per foot

Trenching in rural areas	$15 - $30 per foot
Normal boring	$20 - $30 per foot
Boring through rock	$30 - $50 per foot
Plowing	$ 8 - $15 per foot
Microtrenching	$10 - $15 per foot
Aerial construction (no make-ready)	$ 5 - $ 8 per foot
Aerial make-ready (may vary by street)	$ 5 - $25 per foot

Our Estimated Cost of Fiber Construction.

We've estimated the all-in cost for buried fiber construction to be $135,000 per miles. This price was derived by interviewing Open Cape and others familiar with the cost of burying fiber on the cape. This price includes:

- Construction labor. We've assumed that 10% of the construction in the town would mean drilling through rock. Many of the neighborhoods with buried fiber are on hills where the rockiest soils in the town are located.
- Fiber materials including fiber and conduit
- Installation of fiber access points for connecting fiber to customers. For buried fiber this usually means pedestals (small cabinets in yards that give access to the fiber) or handholes, a buried version where the access is in a cylinder buried in yards.

We've estimated the all-in cost for aerial fiber at $60,000 per mile. This includes:

- Pole make-ready. This is the effort required to make existing poles ready to accept a new fiber. We've estimated this to cost $25,000 per mile. Some of the make-ready cost could be avoided if the town can get the other utilities to trim trees before the start of fiber construction. This is described in more detail immediately below.
- Normal construction labor.
- Fiber materials including access points. For aerial construction, the access points are mounted on poles and pre-spliced so that it's easy to connect a fiber drop to connect to customers.

The $60,000 cost does not include engineering, permitting, construction management, or any construction contingency. Our analysis adds these costs to the cost of the fiber construction.

Are There Any Strategies for Lowering Construction Costs?

A lot of money can be saved during fiber construction if somebody is comparing the cost of these methods for each street in the construction area. If construction companies are allowed to operate unsupervised, they tend to choose the construction method that makes the most money – for example, a crew might push through with boring through rock when there might be a cheaper alternative. A crew might tackle expensive aerial make-ready when it would be cheaper to bore.

We observed that residential streets throughout the Falmouth have a lot of trees that would interfere with aerial fiber construction. A significant portion of our estimated make-ready cost is to undertake this tree trimming as part of the make-ready process. In Falmouth the electric company has done a good job of trimming trees along major roads. But in residential neighborhoods the tree trimming has either fallen behind, or else the electric company only trims to make sure its own wires are freed of the possibility of storm damage.

However, tree trimming is normally the responsibility of existing utilities. The specific responsibility for paying for tree trimming varies by locality. In most of the country the pole owner, which in your case is mostly the electric company is responsible for making sure that tree trimming is kept up to date. Tree trimming is important, because streets with poorly trimmed trees can result in a lot of damage and outages after a bad storm.

If the town were going to undertake building a fiber network, ideally, you'd want to have all the trees well-trimmed before starting construction. If that doesn't happen, then the cost of trimming would have to be borne by the fiber construction project. It sounds like there might be local issues with getting all of the existing utilities to pay their share of tree trimming, but those utilities should be bearing this cost.

Electronics Design Considerations

There are several key considerations when designing the electronics for a last-mile network. The electronics design is key because in can affect how the network is constructed.

- One of the first decisions to be made when looking at a fiber network is determining if you want to use active or passive fiber electronics.
- Another important decision is whether to centralize or distribute the electronics in the network.
- Another decision is the topology of the network deciding between a star versus a ring configuration.
- A final design consideration is to determine whether to use distributed splitter locations or local convergence points for splitter locations.
- A fiber design should also account for the need for future capacity.

Choice of Technology. We elected to design with passive GPON electronics. The advantages of this technology were discussed above. From cost perspective this technology made the most sense in Falmouth because it decreased the size of the fiber bundles in each neighborhood. The electronics for a passive network are also less expensive since this is the primary technology used in the world to deliver residential fiber. In today's market, the cost of using active Ethernet adds at least 15% to the cost of the network electronics.

However, our design also allows for the use of active electronics and every fiber is designed with extra fibers that could be used to bring a dedicated fiber signal up to 10 gigabits to a customer that wants large bandwidth. Effectively, the network design incorporates the best of both fiber technologies.

Distributed Design. Since Falmouth covers a large geographic area, we elected a distributed fiber network design. We subdivided the town into nine construction sectors. In many cases these geographic divisions were based upon the topography of the town where each of the sectors is bounded by geographical barriers.

There were a few reasons to choose the distributed network:

- The so that no customer was more than 12 miles away from neighborhood hut. This distance limitation means 12-miles of fiber along a road, not a 12-mile circle.
- This design makes it easier to activate neighborhoods as the fiber is built. Once one of the nine nodes is completed service can be offered to everybody in that area.

- A distributed network also allows for more redundancy in case a fiber is cut. This will be discussed more below.

We elected to utilize large cabinets for each of the nine neighborhood hubs. This could be upgraded to huts where employees could work indoors by adding perhaps $30,000 to the cost. The huts come as prefabricated units that are already filled with racks and electronics. Each hut includes batteries that provide up to eight hours of emergency power in case of a power outage. Each hut can also be easily connected to a portable electric generator in the case of a prolonged power outage. The huts house the OLT, which are the core electronic platform for communicating with customers. This acronym and the technology will be explained more below.

One of the design decisions to make with a GPON network is the number of customers to place on a single PON. The technology allows up to 64 customers to share a single feeder fiber. We elected to limit each neighborhood PON to 32 customers. The primary reason for this is to ensure that each customer can be provided with a gigabit broadband product if desired. There is enough bandwidth on a single PON (2.4 gigabits download) that there is almost always a gigabit of bandwidth available to any customer at a given second. It's unlikely that most PONs will ever carry 32 customers, because that would require streets where every home subscribes to fiber – but it can happen. This study uses the assumption that the average penetration rate is likely to be between 50% and 60%, and if that was the case, then the neighborhood PONs would be 50% to 60% full on average for the 32 slots possible.

Distributed Splitter Design. We elected to use a distributed splitter design. A splitter is a passive device that splits one fiber to connect to 32 fibers to reach customers. This is the "passive" device in a GPON network because there is no power needed at locations where the fibers are split. The primary advantage of using distributed splitters is that the number of fibers needed to reach each residential street is smaller. If the splitters were all at the neighborhood hut, a fiber would need to go from that hut to each home and business in the sector.

Redundancy. When possible, a good network fiber design should include some consideration for fiber route redundancy. This can most easily be accomplished by the use of fiber rings that include self-healing electronics. A fiber ring is just what it sounds like – this is fiber built to complete a full circle (but that doesn't have to shaped like a circle). Fiber rings are most normally part of the feeder fiber network so that cutting a fiber feeding one neighborhood doesn't knock out service for other neighborhoods. But redundant rings can also be built into distribution fiber serving homes. This is usually only done when there are specific neighborhoods or large business customers willing to pay extra for redundancy.

The big advantage of a fiber ring is that the fiber does not drop out of service from a single fiber cut. The electronics on a ring send all data transmissions in both directions around a ring, meaning that a fiber cut cannot disrupt the flow in data across the ring. In this design we put all of the nine neighborhood cabinets on a fiber ring. This means that if any fiber is cut between the huts that all of the huts will continue to function.

Fiber cuts are inevitable, so the money spent on redundancy pays dividends in the long run. Adding fiber rings and redundancy adds costs because this configuration requires an additional set of electronics to light the redundant ring. This uses a different technology than the fiber used to serve customers. The

electronics needed to light the ring require power, which is why these electronics are all included inside the neighborhood cabinets.

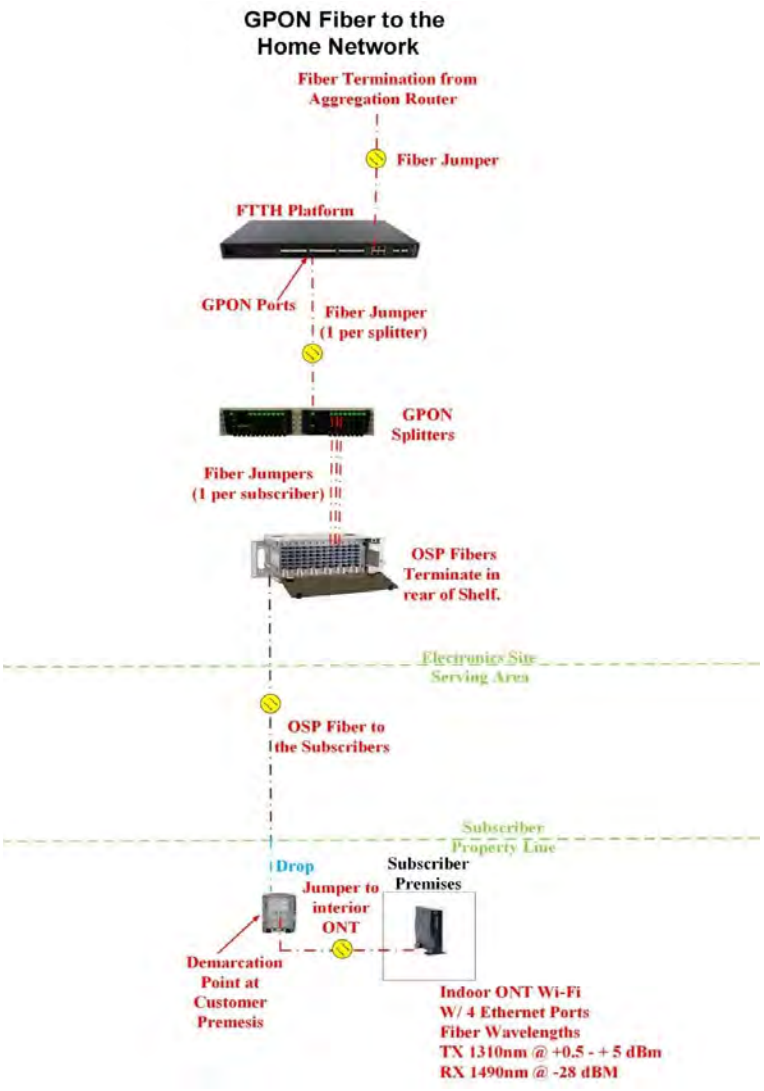
Future Growth. Our design also anticipates future growth. A fiber network might last 50 – 70 years, so the network needs to be robust enough to add on more homes or new neighborhoods in the future. The design provides a 20% buffer to account for future growth. That quantity of extra fibers would be sufficient to handle almost any amount of extra growth. In fiber networks, extra capacity can always be added by beefing up electronics to a higher capacity – so the extra fibers are in place to reach new homes and new neighborhoods. If any of the new neighborhoods grew really large, the combination of extra fibers and faster electronics could handle any growth scenario imaginable.

Connectivity to the Outside World. Every local fiber network must be connected to the outside world where connections are made to the Internet. Falmouth is lucky in that OpenCape has already created the connections from the Cape to Boston and Providence. However, to some degree the entire Cape is somewhat vulnerable to broadband outages since there are only two routes off the Cape to reach the Internet hubs in Boston and Providence. Should a bad storm ever cut both fibers leaving the Cape, the Internet to the whole Cape would go dark.

OpenCape is not the only option for connectivity to the Internet. These same connections could be purchased from Verizon or Comcast, but likely at a higher cost. We've been told that all web traffic leaving the Cape follows the same roads, so there might be no extra safety from buying a connection from the big ISPs – the fibers go along the same roads and might even be in the same fiber bundles.

Components of a GPON Network

The following diagram shows the configuration of the network starting with one of the neighborhood cabinets and ending at a customer.



Core Hub and Connection to the Internet

In Falmouth, any one of the neighborhood cabinets could act as the primary core hub. This would be the hub where a connection is made to reach the internet. Most ISPs would set the core hub nearest or at the location where the employees and technicians work.

We have included a typical map of the backbone network for Falmouth in Exhibit III. This map shows the location of electronics hubs, with one hub in each voting district. For our design purposes we placed each cabinet at the address for voting in each district – but the cabinets can be placed anywhere. The map also shows a theoretical path of the backbone fiber that connects the cabinets. Note that the routing of the backbone could use other streets and that this map is showing only one possibility for the backbone fiber routes.

If an ISP decided to locally provide ISP functions, such as DNS routing to the lnternet, those servers could likely be located near to the core hub. However, an ISP that is already in business probably would not locate these electronics in a new network such as Falmouth. Many ISPs outsource these functions, which are provided from some remote data center.

The core hub would likely be the locations where technicians can connect into the network through network management servers that give technicians access to look at the network. This software gives the technicians the ability to troubleshoot problems and to activate customer products and services such as broadband speeds, telephone service, smart-home services, or other future services.

Optical Line Terminal (OLT)

The electronics used to light the fiber to customers is called an optical line terminal (OLT). This is the top piece of electronics shown on the diagram. Our design places an OLT cabinet in each neighborhood. A typical PLT cabinet is shown below. These range in size from four to six foot tall. These cabinets can be placed outdoors, and if so it's good to put them at secure locations behind fencing. Communities that build networks often place the cabinets inside city-owned buildings. OLTs must be powered, so each cabinet contains equipment needed to provide power, including batteries and other back-up power to keep the network functioning in case of a power outage.

An OLT functions using circuit cards, each of which can serve between 128 and 256 subscribers. Multiple cards can be installed in each OLT chassis and multiple chassis can be installed in each cabinet site if ever needed, meaning that it's easy to scale the network to accommodate future growth. There are multiple vendors that provide an all-inclusive PON solution combining the cabinet and FTTH equipment solution. All vendors meet industry standards and all of them are priced similarly.

PON Splitters

The next component on the network diagram above is a PON splitter. This is a device that can "split" one fiber in order to connect up to 32 customers. On the diagram you can see that there is only one fiber between the OLT and the GPON splitter. Our design places splitters in small cabinets scattered throughout neighborhoods. This design saves the need for significant fiber one fiber coming into a splitter cabinet can serve up to 32 customers. The splitters do not require power, which is why they are referred to as passive. The splitters can be located anywhere in the network where fiber splits are needed to reach customers. Our design would place the splitters as close to customers as possible.

PON Cabinet

If the final design places several splitters in the same location, it's often sensible to install a PON cabinet. The purpose of this device is to neatly arrange and manage the fibers coming into or out of the splitters to make it easy to identify which fiber serves which customer. The primary purpose of a PON cabinet is to accumulate customer connections at strategic points with the goal to minimize the size of neighborhood fibers. Splicing costs increase with the size of fiber bundles, and a good way to hold down costs are to arrange field splitters and PON cabinets to minimize the size of fibers. The need for and location of PON cabinets would be determined as part of a detailed fiber plant design.

Below are two examples of PON cabinets. The first is a large cabinet that would contain enough splitters for a large neighborhood.

More typically, smaller PON cabinets are used, as shown in the following picture. Distributing multiple smaller cabinets maximizes the savings on fiber construction. These cabinets can be placed on the ground, as shown, but also can be mounted on poles where there is aerial fiber.

Fiber Drops

Customer fibers start at PON cabinet sites or small splitter cabinets and reach to every potential customer location. The initial fiber design builds a distribution fiber for every potential customer, plus extra fibers to serve new homes that are built.

To connect a customer to the fiber network, a fiber drop is built from the street to connect to a customer premise. The customer drop is a typically two-fiber cable. Fiber drops can either be fusion spliced to the distribution fibers, and these splices are done inside of a splice case. This is a device that is mounted on poles for aerial fiber or places into pedestals or handholes for buried fiber. The fiber intended for a given customer is terminated at these splice cases and it's relatively easy to splice a drop into the appropriate fiber.

A newer technology replaces a splice case with a connector device that allows drops to be quickly plugged place for the fiber drop. These pre-connectorized drops can save significant installation labor time and the drop snaps into place much like Ethernet cables snap into computers and other devices.

At the Customer Location

The piece of customer electronics used to serve customers is referred to in the industry as an ONT (Optical Network Terminal). This is an electronic device that contains a laser which communicates with the OLT in the neighborhood cabinets. The ONT receives optical light signals from the fiber network and converts the signal to traditional Ethernet on the customer side of the device.

Originally the ONTs were only placed on the outside of buildings in a small enclosure and powered by tapping into the electricity from near to the power meter. But today there is also an ONT that can be placed indoors and that is powered by plugging it into an outlet, much like the cable modems used by cable companies. The cost of the two kinds of units are nearly identical and so the study doesn't choose between the two types of units.

Some companies still put the ONT on the outside of the home to give their technicians 24/7 access to the units. Other providers are electing internal units since they are protected from the weather. The industry is split on this choice, but it appears that internal units are becoming the most predominant choice for new construction. One of the major contributing factors that favors indoor ONTs is that ISPs are tying the ONTs to indoor WiFi routers to provide good wireless connectivity within the home.

ONTs are available in multiple sizes that can be categorized into units designed to serve homes and small business and units designed to serve large businesses. The study assumes that the smaller unit will be used for most customers, including most small businesses. These small ONTs provide for up to four Ethernet streams, which is sufficient for most customers.

Historically, many FTTH networks have been designed with battery back-up for the ONT. However, many small fiber providers have stopped providing batteries. The batteries were historically installed to power telephones in the case of a power outage at the home. Old copper phones received power from the line and could be used when the power was out. However, there is no power in a fiber and thus a battery backup is required to maintain phone service. In 2015 an FCC ruling declared that every voice provider must offer a battery back-up solution for customers that buy telephone service that is not delivered on copper. That ruling said that fiber ISPs only have to make these units available and that customers could be charged the full cost of the unit.

Regardless of the type of ONT (indoor or outdoor), it will be necessary to drill through the side of the home to bring wiring into the premise. ISPs have widely differing ideas on the best way to do this – but most ISPs look for the installation method that requires the least amount of work inside of the customer premise. In the early days of GPON technology there were separate wires run from the ONT to connect to computers, TVs, and telephone wiring. Today, most devices are connected using WiFi, and so the effort to connect to inside wiring is greatly reduced or even eliminated in most homes.

Multi-Dwelling Units (MDUs)

There are just over 1,000 living units in Falmouth that can be characterized as being part of multi-swelling units, meaning that are apartment buildings, condominiums, or townhouses. Many of the MDU units in Falmouth are arranged in such a way that each living unit could be reached as if it was a single-family home. From a broadband perspective, ISPs treat duplexes, small apartment buildings, and townhouses as individual units and use the same electronics and same installation techniques as other homes.

Structures larger than six to eight units must be constructed and served differently. For example, instead of building multiple drops to reach each unit, there would more typically be single larger fiber drop terminated to the inside or outside of an MDU building. Conduit and fiber would then be routed from this splice point to reach each individual unit. There are a number of issues that ISPs face when trying to serve larger MDUs. Following is a discussion of the primary kinds of roadblocks that we see in the MDU market. This is not an all-inclusive list and there will be some MDUs with issues not listed here, but this list should cover most of the kinds of issues encountered with bringing fiber to MDUs.

Exclusive Arrangements. A few years ago, the FCC put some restrictions on cable companies and ISPs from entering into certain kinds of exclusive arrangements with property owners. It was a fairly common practice, for example, for an ISP to share customer revenues with a property owner in exchange for a long-term exclusive right to serve the building. The FCC largely forbade the most egregious practices where ISPs forced exclusivity. However, the FCC did not ban all such practices. For example, exclusive arrangements are still possible when prompted by the property owner, and under FCC rules and various court rulings, property owners are not required to allow access by ISPs to their building.

Financial Roadblocks. Property owners can create financial roadblocks to ISPs, including such practices as:

High Access Fees. Property owners can charge a significant fee to an ISP to gain access to their buildings. This could include excessive fees to connect facilities into basements or rooftops. Alternatively, they might charge high rent to use communications spaces.

Forced Revenue Sharing. Property owners might demand that any ISP entering their building must share customer revenue with them. This is of particular concern for a municipal provider because there is a good chance that such practice wouldn't be allowed. CCG has numerous municipal clients that could not find a way to pay commissions in the same manner as is done by commercial ISPs.

Partial Services Allowed. Sometime property owners include some basic level of telecommunications service in the rent. For example, they might already include a video package that they receive from satellite and distribute to apartment units. Such arrangements might be a financial roadblock if they make it hard for ISPs to profitably provide other services to tenants.

Ownership of Existing Communications Infrastructure. Property owners don't always own the existing telecom infrastructure in a building. Sometimes such infrastructure was installed by the cable company or other ISP and those entities maintain ownership through a contractual

arrangement with the property owner. There are several categories of assets where ownership by somebody other than the property owner can be a roadblock.

Existing Wiring. A cable company, telephone company, ISP, or CLEC might own the existing telephone copper, coaxial cable, category 5 cables, or fiber. Private owners don't have to make their facilities available to anybody else. In some cases, businesses within multitenant buildings own their own wiring inside their rented space, but that is rarely a roadblock for the business owner to choose to change service providers.

Normally a fiber overbuilder is not going to want to use the existing wiring if they want to offer gigabit speeds. However, there are times when that might be desirable. For example, one of the technology options explored in this report is using G.Fast, which can be delivered over telephone copper or coaxial cable. While this doesn't deliver a full gigabit, it can deliver 300–400 Mbps broadband, which many property owners would find desirable. However, that technology can't be used if the wires are owned by somebody other than the business owner. There are also buildings which will be 'pre-wired' for broadband. Most of these will have category 5 or category 6 cable, although new building might luckily have fiber. However, there is the same issue if this wiring is owned by somebody other than the MDU owner.

Existing Conduit. An existing ISP may have installed conduit or ducts within a building and won't allow access to other ISPs. This could be conduit between floors of a building (referred to as riser infrastructure), conduits between different buildings in a campus environment, or conduit distributing cables along hallways and other pathways.

Other Existing Infrastructure. An existing ISP might own other key telecommunications infrastructure. This might include communications cabinets or boxes that tie into existing wiring. It might mean they own the racks that take up all of the existing space in a telecommunications closet. Alternatively, it could mean towers or other rooftop infrastructure.

Entrance Facilities. Larger buildings will often have an existing entrance facility of some sort used to provide access to all utilities from the street into the building. This could be owned by the property owner or owned by one or more of the existing utilities, including non-telco utilities such as the electric or water utility. It's sometimes an issue to gain access to these entrance facilities. For example, an electric utility might be leery of allowing more than one ISP into their existing facility due to perceived safety or risk issues.

Pathways to Reach Units. One of the biggest issues faced in multi-tenant buildings is how to provide the broadband connection between the building entrance and individual tenants. There are numerous issues associated with this access.

Unusable Existing Wiring. Even when there is usable wiring in a building it might not be usable for a new ISP. For example, there are many different ways that a building can be wired—there can be "home-run" wiring that has a separate path from a central hub to each tenant, or at the other extreme wires can be strung in series through multiple

apartment units. Some existing wiring schemes create technical roadblocks for using the existing wiring for G.Fast.

Riser and Other Conduit. Often the pathways to tenants are blocked due to lack of usable infrastructure. For example, there might be existing riser conduit between floors that is already full, with no room for additional cables. Moreover, there might not be room to add another riser conduit.

Owner Requirements. Property owners often have other restrictions that make it difficult to enter and wire buildings.

Buried Utilities. Property owners might not allow any outdoor wires above ground. This would mean that drops and connections between buildings must be buried. In many cases, that would mean boring connections under driveways and parking lots—which is not always a safe process since the locations of other utilities are not always well known or marked on private property. The expected industry requirements for utilities using public rights-of-way may not be followed on private property. For example, buried conduit and fiber in public rights-of-way generally require some use of a technology that allows the infrastructure to be detected by anybody trying to locate existing technology. However, infrastructure without such marking technology would be invisible to a locator.

Aesthetic Issues. Probably one of the biggest roadblocks encountered when wiring MDUs is the aesthetic requirements of the property owner. For example, one of the more common techniques for adding new fiber in hallways is to place the wiring in the corners of the ceiling and cover it with some kind of protective strip. Sometimes the only path to reach units might be to string wires in some manner on the outside of the building. If a property owner won't allow the use of these techniques for aesthetic purposes then it either means the building can't be wired with fiber, or it can be wired only at a much higher cost than expected.

Boxes on the Outside of Buildings. Property owners might not allow boxes, cabinets, or other equipment terminals to be attached to the outside of buildings or even to rooftops.

Access Issues. Another impediment encountered by ISPs is one of access, or the ability to undertake the steps needed to best serve tenants. This includes:

Type of Building Construction. There have been numerous construction techniques used over the years in building MDUs, and some of the methods used in older buildings can add significant costs to serving the buildings. For example, older buildings might have old wood and plaster walls between units and for ceilings that can add cost or make it impossible to drill holes for new wires. Some old buildings have solid concrete slabs between floors through which the property owner might not allow drilling of new holes.

Access to Communications Space. ISPs generally need a space within a multi-tenant building to place hub electronics needed to serve the building. Such equipment is most commonly placed in a space reserved for telecommunications equipment that might be in

a small room or closet. Problems can arise when existing communications space is full and there isn't room for a new ISP.

Access to Power. ISPs need access to power. This can present a problem if it's hard to provide separate electric meters or to otherwise supply the specific power needs of the ISP.

24/7 Building Access. Property owners often make it a challenge for an ISP to gain access to their equipment.

Access to Apartment Units. Property owners sometimes create roadblocks making it hard to ISPs to install or repair facilities inside of apartments. Some property owners only allow access when accompanied by an MDU employee. That's something the MDU might charge for. More commonly there can be costly delays when there is nobody available to accompany a technician.

Restrictions on Sales and Marketing. It's fairly routine that ISPs are not allowed to sell or market inside MDUs in the same manner that is done for single-family homes. For example, there might be no solicitation rules in MDUs that don't allow for door-knocking sales campaigns.

Security Issues. ISPs want their equipment to be kept safe from the public and from other ISPs. This means providing secure space. Ideally that means being able to put a cage or lockable box around gear in space used by multiple service providers. Sometimes this is not possible to do because of space or other limitations.

Administrative Issues. ISPs have identified administrative issues that present challenges such as:

- Business Requirements. Property owners often have specific legal or other issues they expect ISPs to follow:
- Surety. Property owners may require ISPs to be bonded or to have a set level of insurance. This kind of bonding or insurance is not something that many ISPs are able or willing to obtain, making it a challenge to satisfy such requirements.
- Contracts Required. Property owners may require ISPs to agree to a standard contract before entering a building. This can be a problem because there are often some legal terms in standard commercial contracts that municipalities are unable to legally agree to.
- Dispute Resolution. Property owners might want an ISP to agree to arbitration or some other way to solve disputes that might be a problem for a municipality.

Conclusions. It's important to understand these various roadblocks because almost any item on this list could add to the complexity and cost of bringing fiber to an MDU. For example, there might be a willing MDU owner that wants fiber, but then once they realize that adding the fiber will violate their aesthetic requirements, it may turn out that it's too costly to get fiber to the building.

However, sometimes it's even smaller issues that might make it impossible to serve a given MDU. For example, it can be impossible to serve a building if the overbuilder doesn't have a secure location to place core electronics or doesn't have access to building entrance facilities.

Most ISPs that serve MDUs have a detailed checklist listing the specifics of the above issues. An ISP will generally walk through the MDU and determine the best wiring plan and then go over the checklist with the MDU owner. It's not uncommon to find one or more issues that are a roadblock to implementation. Sometimes roadblocks can be overcome by the ISP spending more money to solve the issue. It's also the case that sometimes the roadblocks cannot be overcome.

It is all of these reasons that make it impossible to discuss the "typical" cost to rewire an MDU. Until the full checklist and design are done, an ISP won't understand the issues present at a given MDU. In the analysis as part of this report we used "typical" costs for wiring MDUs. However, these costs only represent the costs of getting to buildings where the access is reasonable. Our analysis assumes that there are some buildings where an ISP will not gain access. That could be for the reasons discussed above—there might be an arrangement with another ISP that keeps out the overbuilder, there might be a physical impediment that makes it too costly to rewire, or a property owner might have aesthetic, financial, contractual, or other requirements that can't be made to work for a municipal network provider.

5G and Fiber

The RFP asked the question of whether there is an economic case and benefit from leveraging a fiber network to provide better 5G coverage in a community. It's a great question and is one that fiber network owners everywhere are wrestling with.

Elsewhere in this report we discuss how the term 5G is used to describe several completely different technologies, so this discussion needs to start by defining the 5G use being discussed.

One use of 5G is to provide fiber-to-the-curb and provide gigabit broadband to homes. That technology builds fiber on streets and then used wireless transmitters to beam the broadband for the last 100 feet to reach homes or businesses. It's possible that by the time that you build a fiber network in Falmouth that this could become an option for the way you build the network. For now, this technology is not readily available to a new fiber builder. Verizon is the only company in the US doing this to any extent and they are using a proprietary technology and licensed spectrum – two things other ISPs can't mimic. But this will eventually become a commercially available technology, and at that point, it would be an alternative to the PON technology used in our analysis.

If there was a new fiber network built in the town it would be extremely unlikely that the fiber owner would lease fiber capacity to another ISP that wanted to offer this form of 5G. That would be allowing a rival ISP to benefit from your new fiber. This would be the equivalent of Comcast allowing their rival Verizon to somehow offer faster broadband in Falmouth. This is likely to never happen and it would be a bad decision to enable a competitor.

Another use of 5G is the way that Verizon and AT&T are offering 5G hotspots in downturn urban centers. This technology places outdoor hotspots, fed by fiber, and then beams gigabit speed broadband for a few hundred feet around each hotspot. These companies are using millimeter wave spectrum to

transmit the broadband, and that means customers using this service must but special phones or devices that can use the specific frequencies.

There may come a time when this becomes a standardized product, and perhaps this will be built into cellphones, or at least built into dongles that could support a laptop or tablet. If it becomes standardized, the new fiber provider could either offer this directly or else could lease fiber bandwidth to support an ISP that specializes in this technology. There is a good chance this technology fades into history because the broadband delivered is extremely squirrelly. The frequencies used won't even pass through a human body and you can block the signal by being turned the wrong way away from the transmitter. But if this ever becomes a mature, workable technology, then there would be the opportunity to monetize it.

The predominant use of 5G is always going to be 5G cellular traffic delivered to cellphones. Anybody building a new network should explore the possibility of providing transport to cellular sites. The big cellular companies have always provided cellular service from transmitters located on tall towers. However, for 5G to be most effective, the cellular companies are already installing small cell sites scattered throughout a town. It would be surprising if there are not already small cell sites in Falmouth since the cellular network must be under big stress in the summer when all of the tourists are in town.

What is not known for a given community is if the cellular companies would be interested in using a new fiber network. For example, Verizon has largely adopted the strategy of building their own fiber for 5G, particularly in places where they are already the incumbent telephone company. Verizon already owns some fiber around Falmouth that is used to feed DSL huts or used to reach to other large customers. Verizon might be able to construct a 5G network based upon that existing fiber, supplemented by additional fiber construction.

For now, the only two other cellular companies are AT&T and T-Mobile. Verizon and AT&T have a nationwide arrangement to swap tower space, and it's possible that if Verizon builds small cells in Falmouth that AT&T might share the same locations. For every cell site that Verizon provides in Falmouth, AT&T would provide one in some other city where AT&T is the incumbent telephone company. In the past, T-Mobile was not a big participant in these shared cell site locations, but they recently purchased Sprint that widely shared cell sites with AT&T. That means that it's conceivable that all three companies share cell sites in the town and wouldn't be looking to lease additional fiber. All of the cellular companies are working hard to eliminate fiber leases, which are their biggest expense.

There is one new cellular player. Dish Networks is building a nationwide cellular network and it's almost certain that they will appear in the next three or four years in Falmouth. At this early stage there is no way to predict how they will get cell sites, since the company is starting from a position of having zero cell sites.

There is one other wild card in that Comcast is now in the cellular business. The company currently resells cellular signal purchased from T-Mobile, but Comcast has announced that they will deploying cell sites in markets where it can save them money and increase margins. Comcast likely has more fiber in Falmouth than Verizon, so Comcast is likely going to be able to deploy small cells in Falmouth if that's a market they plan to migrate to facility-based 5G. This means it's unlikely that Comcast would lease fiber space from a new network, but instead Comcast might sell capacity to T-Mobile or Dish Networks.

This means that there is a wide range of possibilities for the way that a new fiber network might benefit from 5G. It's possible that one or more of the cellular carriers would choose to lease capacity on a new fiber network, particularly if the cost of using the new fiber is a lot less than the cost of building fiber. But the other extreme is also possible in that there may be no cellular companies interested in using a fiber network in Falmouth even if it was in place today. The margins on the cellular business have been tightening due to price competition between the carriers. It's expected for price competition to intensify, particularly when Dish Networks enters the market. That means the cellular companies will try hard to not have to lease fiber transport. They would prefer to build, share, or swap fiber rather than pay outside fiber networks for access.

Using the OpenCape Backbone Fiber

OpenCape owns a fiber network today that reaches into various corners of Falmouth. OpenCape has built fiber to serve the largest broadband users in the community such as the hospital, schools, the business park, the downtown business corridor, and other larger businesses throughout the community. The RFP asked if the project would benefit by using that existing fiber..

The new fiber network anticipated by our analysis would be built to pass every home and business in the town. That means that new fiber would have to be built down every street to reach homes and businesses along the street. That is going to mean that the new network is going to have to be built along the same roads as the existing OpenCape fiber.

It's possible that there could be some savings for sharing in OpenCape fiber. Most OpenCape fiber on main routes in Falmouth have 128 fibers and secondary later fibers mostly have 72 fibers. This means that there are likely a significant number of open fibers on OpenCape that could be made available for a fiber network to reach every home and business.

To be conservative, in our study we assumed that that a new fiber network would build on all of the streets in the city. There are both operational and financial issues involved with using fiber on somebody else's network. The following list of issues would have to be considered if some entity other than OpenCape is the operator of a new fiber network. Some of these issues go away if OpenCape is the ISP chosen to serve the whole city.

- OpenCape is using some of the fibers on its network and likely would want to reserve other fibers for future uses. It's also prudent to always keep unused fibers on every route which can be used in the future to replace fibers that go bad over time. The first step in deciding to use OpenCape fibers would be to determine how many fibers could be made available on each route for a new citywide network. On any route where more fibers are needed than are available on OpenCape, the right path forward would be to build a new fiber on the route.
- There is always a question of cost. OpenCape would either want to sell or lease the fibers to the new venture, and such costs would have to be carefully weighed against the cost of building new fiber. Fiber projects already have slim cash margins for the first ten years, so any payment for fibers would need to be done in such a way as to minimize early-year cash outlays. That means that an outright purchase of fiber, or else long-term leases that pre-pay the lease are probably the most attractive option, assuming that cost is lower than the cost of building new fiber.
- There are always going to be operational issues between carriers sharing a fiber sheath. The most common practice in the industry is for a fiber owner to not allow any outside technicians to touch its fiber – meaning the fiber owner must do all work that involves touching a fiber. This can

create major operational concerns if the fiber owner is not as responsive as the ISP serving customers in the city.

This means that the idea of using OpenCape's fiber would have to examined on a route-by-route basis. There are likely some routes where it will make sense for a new ISP to use the OpenCape fiber and there will be cases where it won't make sense.

One of the most obvious ways to take advantage of the OpenCape fiber would be to use it as the backbone that already reaches into many of the neighborhoods in the town. If a core backbone could be established in the OpenCape fiber the construction process would be accelerated across the city as new construction could connect customers in multiple parts of the town at the start of construction.

There is the final complication that OpenCape and a new fiber builder would be rivals. In the interviews we conducted, many OpenCape customers told us they are paying a premium price for broadband. The OpenCape pricing is premium because it provides dedicated access to most customers – meaning broadband dedicated fully to the use of a given customer. If a new ISP builds fiber everywhere it will also offer dedicated bandwidth, but the predominant product on a new network will be shared bandwidth. Many OpenCape customers might be willing to swap to a lower-priced product on the new fiber network. The businesses using OpenCape today are willing to pay a premium prices for fiber broadband because that's the only alternative – but it's likely that at least some of those customers will be clamoring for a new fiber builder to bring them a cheaper alternative. Of course, there is also the possibility that OpenCape becomes the partner ISP – and all such issues disappear.

C. Competing Technologies

Existing Technologies

There are several technologies used in the town today to deliver broadband. Each of these technologies will be explained below.

- Verizon serves the town with copper telephone wires using DSL technology.
- Comcast uses hybrid fiber/coaxial (HFC) technology to provide the triple play services.
- OpenCape and the incumbent providers use active Ethernet technology to bring fiber directly to large businesses, schools, etc.
- OpenCape is using GPON fiber-to-the-premise technology to serve small businesses. This is the same technology we considered for a whole-town build.
- Some homes get broadband using the data on their cellphone plans.

DSL over Copper Wires

Verizon uses DSL (Digital Subscriber Line) to provide a broadband path over a copper network. The copper networks were built between the 1950s and early 1970s. The copper networks were originally expected to have an economic life of perhaps forty years and have now exceeded the economic life of the assets. The copper networks are deteriorating as a natural process of decay due to sitting in the elements. Maybe even more importantly, the copper networks have deteriorated to some extent due to neglect. Verizon and the other big telcos started to cut back on maintenance of rural copper in the 1980s as the companies were deregulated from some of their historic obligations. At some point the copper networks will die even though regulators continue to act like they will keep working forever.

DSL works by using frequency on the copper that sits just above the frequencies used for telephone service. There are different kinds of DSL standards, each of which has a different characteristic in terms of how much bandwidth they deliver and how far the signal will travel. The most efficient forms of DSL can deliver up to 24 Mbps service over a single telephone wire. Verizon is able to bond two telephone wires together and offer speeds up to 48 Mbps. Most of the DSL in the town is of older varieties and delivers slower speeds.

The most important characteristic of DSL is that data speed delivered to customers decreases with the distance the signal travels. This means that the DSL speeds differ throughout the town, and even within a neighborhood.

The general rule of thumb is that most of the types of DSL can deliver a decent amount of bandwidth for 2 to 3 miles over copper. Verizon transmits DSL from their historic central offices. They also might transmit DSL from deeper in the copper network from field cabinets placed in various neighborhoods around the town.

DSL signal strength is also affected by the quality of the copper. The newer the copper and the larger the gauge of the copper wire, the better the signal and the greater the bandwidth. Many of the copper wires in the town are old and have gotten water damage over the years and won't carry the full amount of bandwidth.

Hybrid Fiber Coaxial Network

Comcast is the incumbent cable company in town. The technology used in the Comcast network is referred to as Hybrid Fiber Coaxial (HFC). Hybrid refers to the fact that an HFC network uses a fiber backbone network to bring bandwidth to neighborhoods and a copper network of coaxial cable to deliver service to customers. HFC networks are considered lean fiber networks (meaning relatively few fiber strands) since the fiber is only used to deliver bandwidth between the headend core and neighborhood nodes. At each node is a broadband optical receiver that accepts the fiber signal from the headend and converts it into a signal that is sent over coaxial cable to reach homes and businesses.

The coaxial copper wires in the Comcast network are also aging, similar to the telephone copper wires. The coaxial network in Falmouth was likely built in the 1970s. Coaxial cable networks exhibit signs of aging sooner than telephone copper networks because the wires act like a huge antenna, and older networks attract so much interference and noise that it become harder to transmit the signals through the wires.

An HFC system handles delivery of customer services differently than an all-fiber network. For example, in an HFC network, all of the cable television channels are transmitted to every customer and various techniques are then used to block the channels a given customer doesn't subscribe to.

In an HFC network all of the customers in a given node share the broadband in that node. This means that the numbers of customers sharing a node is a significant factor - the fewer the customers, the stronger and more reliable the broadband signal. Before cable systems offered broadband, they often had over 1,000 customers on a node. But today, the sizes of the nodes have been "split" by building fibers deeper into neighborhoods so that fewer homes share the data pipe for a given neighborhood. The

architecture of using neighborhood nodes is what has given cable companies the reputation that data speeds slow down during peak usage times, like evenings. However, if nodes are made small enough, then this slowdown doesn't have to occur.

The amount of bandwidth available to deliver Internet access that is available at a given node is a function of how many "channels" the cable company has dedicated to data services. Historically a cable network was used only for television service, but in order to provide broadband the cable company had to find ways to create empty channel slots that no longer carry TV programming. Most cable systems have undergone a digital conversion, done for the purpose of freeing up channel slots. In a digital conversion a cable company compresses video signals and puts multiple channels into a slot that historically carried only one channel.

The technology that allows data to be delivered over an HFC system follows a standard called DOCSIS (Data Over Cable Interface Specification) that was created by CableLabs. Likely around a decade ago Comcast upgraded to the DOCSIS 3.0 standard that allows them to bond together enough channels to create broadband speeds as fast as about 250 Mbps download. A few years ago Comcast upgraded most of their networks nationwide to a new standard, DOCSIS 3.1, that theoretically allows all of the channels on the network to be used for data and which can produce broadband speeds as fast as 8–10 Gbps if a network carried only broadband and had zero television channels. Since there are still a lot of TV channels on a cable network, most cable companies have increased the maximum broadband speeds to between 500 Mbps and 1 Gbps using DOCSIS 3.1. We can tell that Falmouth was upgraded due to the availability of broadband products being sold that vary between 400 Mbps and gigabit speeds.

One limitation of a DOCSIS network is that the standard does not allow for symmetrical data speeds, meaning that download speeds are generally much faster than the upload speeds. This is an inherent design characteristic of DOCSIS 3.0 and 3.1 where no more than 1/8 of the bandwidth can be used for upload. Earlier in the report was a lengthy discussion about the upgrade speed crisis that has arisen during the pandemic. The cable companies are likely hoping that issue will diminish in importance at the end of the pandemic.

CableLabs has developed an upgrade being called DOCSIS 4.0 that will allow for symmetrical gigabit data speeds. This will require even more empty channel slots on a cable network and the new standard assumes that cable company will increase total system bandwidth of the network to at least 1.2 GHz of bandwidth. The gear needed to upgrade to DOCSIS 4.0 won't hit the market for at least two or three years. Most of the big cable companies have already said they are not interested in upgrading immediately to the new standards since the upgrades are expensive. Cable companies will ultimately face a big decision, because if they are going to upgrade to DOCSIS 4.0 they also might instead consider the leap to fiber. Most analysts think that upgrade is likely decades away, but most think that cable companies will eventually migrate to fiber. That's not quite so obvious to me – cable companies strive to minimize capital costs and are likely to milk the current networks for as long as possible. Like with any big upgrade, Comcast would be far more likely to upgrade the big urban markets before secondary markets like the Cape.

There is a distance limitation on coaxial cable. Unamplified signals are not generally transmitted more than about 2.5 miles over a coaxial network from a network node. This limitation is based mainly on the number of amplifiers needed on a single coax distribution route. Amplifiers are needed to boost the signal strength for coaxial distribution over a few thousand feet. Modern cable companies try to limit the

number of amplifiers on a coaxial route to five or less since adding amplifiers generally reduces broadband speeds.

Metro Ethernet

Metro Ethernet is the primary technology used to deliver large bandwidth to a single customer over fiber. This is the technology used by OpenCape to deliver broadband to some of the larger businesses and anchor institutions in the community. The technology is likely used by Verizon and Comcast also. This technology is often also referred to as active Ethernet.

Metro Ethernet technology generally uses lasers that are capable of delivering 1 gigabit or 10 gigabit speeds, although lasers as fast as 100 Gbps are available. ISPs can choke these speeds to slower levels based upon what a customer is willing to pay for.

Many ISPs dedicate a fiber for each metro Ethernet customer, but that's not mandatory. For example, an ISP could light a fiber to deliver 10 Gbps and string that fiber to multiple customers each buying 1 Gbps service.

Cellular Broadband.

The survey showed that about 4% of residences use only their cellphone for home broadband. There are obvious limitations on cellphone for home broadband. The amount of broadband capacity is small compared to wireline broadband. Most standard cellular plans provide 10 gigabytes of broadband usage per month or less. Even the unlimited plans offer only 20 – 25 gigabytes per month of broadband. One of the limitations on unlimited data plans is that they can only be used to tether to computers or other devices for a limited amount of capacity per month – most of the data in the plan must be consumed by the cellphone.

Customers can buy more broadband when they exceed the subscribed capacity, but this is some of the most expensive broadband in the world, typically priced at $10 per extra gigabyte. While it would unusual for somebody in the town to spend a lot for cellular data plans, CCG has talked to rural customers across the US who have monthly cellular data bills in excess of $500 per month if they use cellular data to support students doing homework.

AT&T and T-Mobile have started to offer what they call fixed cellular data plans. With these plans the carriers place a small dish on a customer home and use cellular frequencies to deliver fixed wireless broadband. The fixed broadband is for normal home consumption – it uses cellular frequency but is not delivered to cellphones. These plans have much larger data caps than on regular cellular plans. For example, the AT&T fixed cellular plan has a monthly data cap of 215 gigabytes. It's not likely that they are offering these plans in the town today. Currently, AT&T only offers this plan in places where they are the incumbent telephone company. T-Mobile has said they will offer this product nationwide if they are allowed to merge with Sprint – that merger was approved by the courts in February 2020, so perhaps this will become available in the next few years.

Fixed 4G Cellular Wireless

As this paper was being written, Verizon announced a new wireless broadband product that might show up in the Falmouth market. The product is called "LTE Home Internet." The product is easily explained. Verizon will be delivering unlimited data using the cellular 4G LTE network. Customers must buy a receiver from Verizon for $240, although for now they are offering a $10 discount for 24-months which returns the cost of the box over two years. The product is $40 per month for a household that is buying a Verizon wireless product that costs at least $30 per month. Non-Verizon wireless customers pay $60 per month. There is free tech support for setup issues for 30-days, implying that tech support will entail a fee after that.

Verizon touts the product as delivering 25 Mbps download speeds, with bursts as high as 50 Mbps. Verizon is launching the product in three markets – Savannah, GA, Springfield, MO, and the Tri-cities area at the area near the borders of Tennessee, Virginia, and Kentucky.

It appears that the product is intended to help Verizon replace rural DSL customers, and to let Verizon compete for broadband customers anywhere they operate on a cellular tower. Verizon has made it known for many years that the company wants to walk away from rural copper networks. But the company has also been busy decommissioning copper networks in suburbs up and down the east coast. In cities Verizon can walk away from copper networks by expanding FiOS on fiber. But the company is highly unlikely to be looking at building new FiOS network on the Cape. Verizon largely stopped building FiOS fiber in 2010, although the company built small amounts since then. Verizon has repeatedly said that they don't anticipate building more fiber-to-the-home.

There is speculation that Verizon will walk away from all copper within a decade. If they do that in Falmouth, then the only real ISP left would be a Comcast monopoly.

This new product could be Verizon's answer of what follows DSL on copper. The product just needs a strong cellular signal, and if the signal isn't strong enough in a community like Falmouth it wouldn't be that expensive for Verizon to beef up the cellular network. This product offers speeds that are promised to be around 25 Mbps with burst up to 50 Mbps. That's superior to the DSL speeds we saw in Falmouth during this study.

The only question is if Verizon's cellular network is robust enough to maintain the cellular network while layering on fixed broadband – particularly during the summer when the cellular network is stressed.

But Verizon needs to have a replacement product before state regulators would allow them to tear down copper – and this new product might be an experiment with that product.

T-Mobile is supposedly launching a similar product. As part of its merger with Sprint the company promised to provide fixed 4G wireless broadband that will cover over 50% of the homes in the country. This would be similar to the Verizon product and would be offered in many places where T-Mobile has cellular towers. However, I've already seen articles saying that T-Mobile is trying to wriggle out of its merger promises, blaming the pandemic. However, there is a long tradition in the country of carriers not fulfilling promises made the FCC and the States during merger talks.

Future Technologies

This section looks at new technologies that are likely coming within the next few years to the US.

Next Generation Fiber Technologies. There are two next-generation and competing fiber-to-the-home technologies that will allow connections to customers to be upgraded to 10 Gbps broadband and even faster - NG-PON2 or XGS-PON. The current widely deployed GPON technology will eventually hit a technology wall. The technology delivers 2.4 Gbps downstream and 1 Gbps upstream for up to 32 customers, although many networks are configured to serve 16 customers at most. This is still an adequate amount of bandwidth today for residential customers and can easily provide a gigabit product to every customer if desired.

GPON technology is over a decade old, which generally is a signal to the industry to look for the next generation replacement. This pressure usually starts with vendors who want to make money pushing the latest and greatest new technology - and this time it's no different. After taking all of the vendor hype out of the equation it's always been the case that any new technology is only going to be accepted once that new technology achieves an industry-wide economy of scale. That means being accepted by at least one large ISP.

The most talked about technology is NG-PON2 (next generation passive optical network). This technology works by having tunable lasers that can function at several different light frequencies. This would allow more than one PON to be transmitted simultaneously over the same fiber, but at different wavelengths. That makes this a complex technology with multiple lasers and the key question is if this can ever be manufactured at price points that can match other alternatives.

The only major proponent of NG-PON2 today is Verizon, which recently did a field trial to test the interoperability of several different vendors including Adtran, Calix, Broadcom, Cortina Access, and Ericsson. Verizon seems enamored with the idea of using the technology to provide bandwidth for the small cell sites needed for a 5G network. However, the company is not building much new residential fiber. They announced they would be building a broadband network in Boston, which would be their first new construction in years, but there is speculation that a lot of that deployment will use wireless 60 GHz radios instead of fiber for the last mile.

The market question is if Verizon can create enough economy of scale to get prices down for NG-PON2. The whole industry agrees that NG-PON2 is the best technical solution because it can deliver 40 Gbps to a PON while also allowing for great flexibility in assigning different customers to different wavelengths. Still, the best technological solution is not always the winning solution and cost is the greatest concern for most of the industry. Today the early NG-PON2 electronics are being priced at 3 - 4 times the cost of GPON, due in part to the complexity of the technology, but also due to the lack of economy of scale without any major purchaser of the technology.

Some of the other big fiber ISPs like AT&T and Vodafone have been evaluating XGS-PON. This technology can deliver 10 Gbps downstream and 2.5 Gbps upstream—a big step up in bandwidth over GPON. The major advantage of the technology is that is uses a fixed laser which is far less complex and costly. In addition, these two companies are building a lot more FTTH networks than Verizon.

While all of this technology is being discussed, ISPs today are can deliver 10 Gbps data pipes to customers using Active Ethernet technology. For example, US Internet in Minneapolis has been offering