ctc technology & energy

engineering & business consulting

Broadband Strategic Plan

Prepared for Los Alamos County

DRAFT | January 2023

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1 Executive summary

Los Alamos County, New Mexico, commissioned this report to support its goal of improving access to high-quality, future-proof broadband for residents and businesses. The County engaged CTC Technology & Energy (CTC), an independent consultant, to assess the availability of broadband infrastructure and services in the County, engage stakeholders and residents to identify their needs and challenges around broadband, and evaluate the technical and business cases for an open-access fiber-to-the-premises (FTTP) network in the townsite of Los Alamos (the Townsite) and White Rock.

The project team performed the following tasks over the course of the engagement:

- Analyzed publicly available data from the Federal Communications Commission (FCC) and internet service providers (ISP) to evaluate the County's broadband market (infrastructure and services) and identify unserved and underserved areas
- Gathered feedback and data from stakeholders and the community through a series of meetings, a scientifically valid mail and online survey of residents, and an online speed test survey
- Prepared a design and cost estimate for a candidate FTTP network that could meet the County's goal
- Evaluated potential state and federal funding opportunities and business models for such a network
- Re-examined the "Community Broadband Network Business Plan" prepared for the County by Crestino Telecommunications Solutions in February 2013 in light of the significant changes in the broadband market over the past decade (e.g., advancements in technology; new opportunities for partnerships and federal funding) and lessons learned by small and medium communities that have deployed fiber in the interim

The following sections present key findings from the project team's work.

1.1 Much of the County's population is served with broadband

Much of the Townsite and White Rock, which are home to more than 95 percent of the County's population, are served by Comcast's cable network—which delivers service of at least 100 Mbps download and 20 Mbps upload (100/20). CenturyLink also provides digital subscriber line (DSL) services with lower download speeds in some of the areas in and north of the Townsite, as well as south of White Rock.

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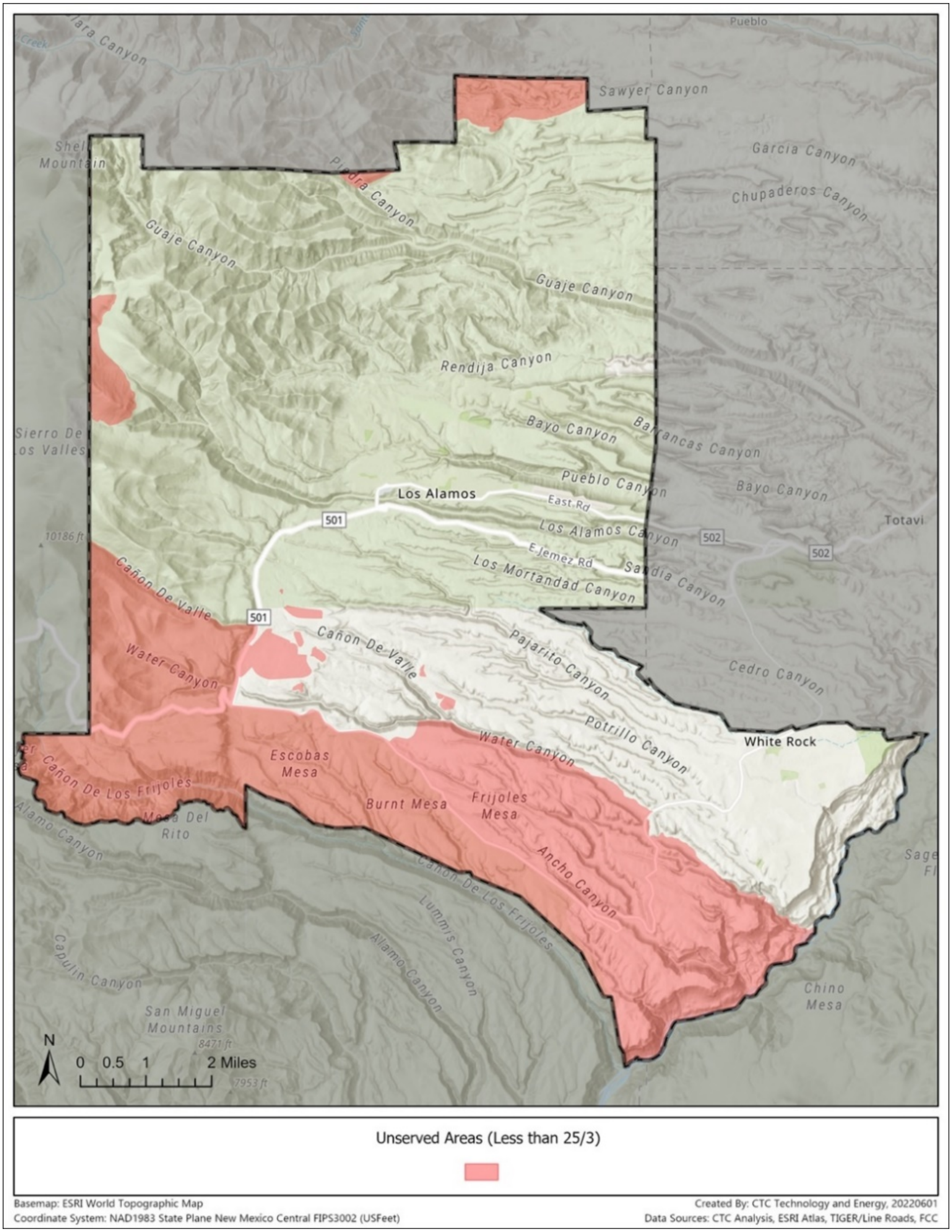
Fiber service in the County is limited. Los Alamos Net offers fiber services in small downtown areas of the Townsite, Quemazon, and Hawks Landing, while CenturyLink serves at least one recently constructed residential multi-dwelling unit in the Townsite.

Due to the lack of competition, the broadband service tiers available to customers in the County are inferior to those in fiber-rich markets—most notably in terms of upload speeds. A lack of competition may also contribute to low investment in network upgrades, and less incentive to offer promotions to customers or lower the price of service.

1.2 Unpopulated areas outside the Townsite and White Rock are unserved or underserved

While residents in the Townsite and White Rock are served, unpopulated portions of the County located along the southern Route 4 corridor and west of 501, as well as a few areas to the west and north of the County, are unserved (i.e., residents who live there do not have access to service of at least 25 Mbps download and 3 Mbps upload, or 25/3). These areas are shown in Figure 1.

Figure 1: Unserved areas (lacking 25/3 Mbps service)



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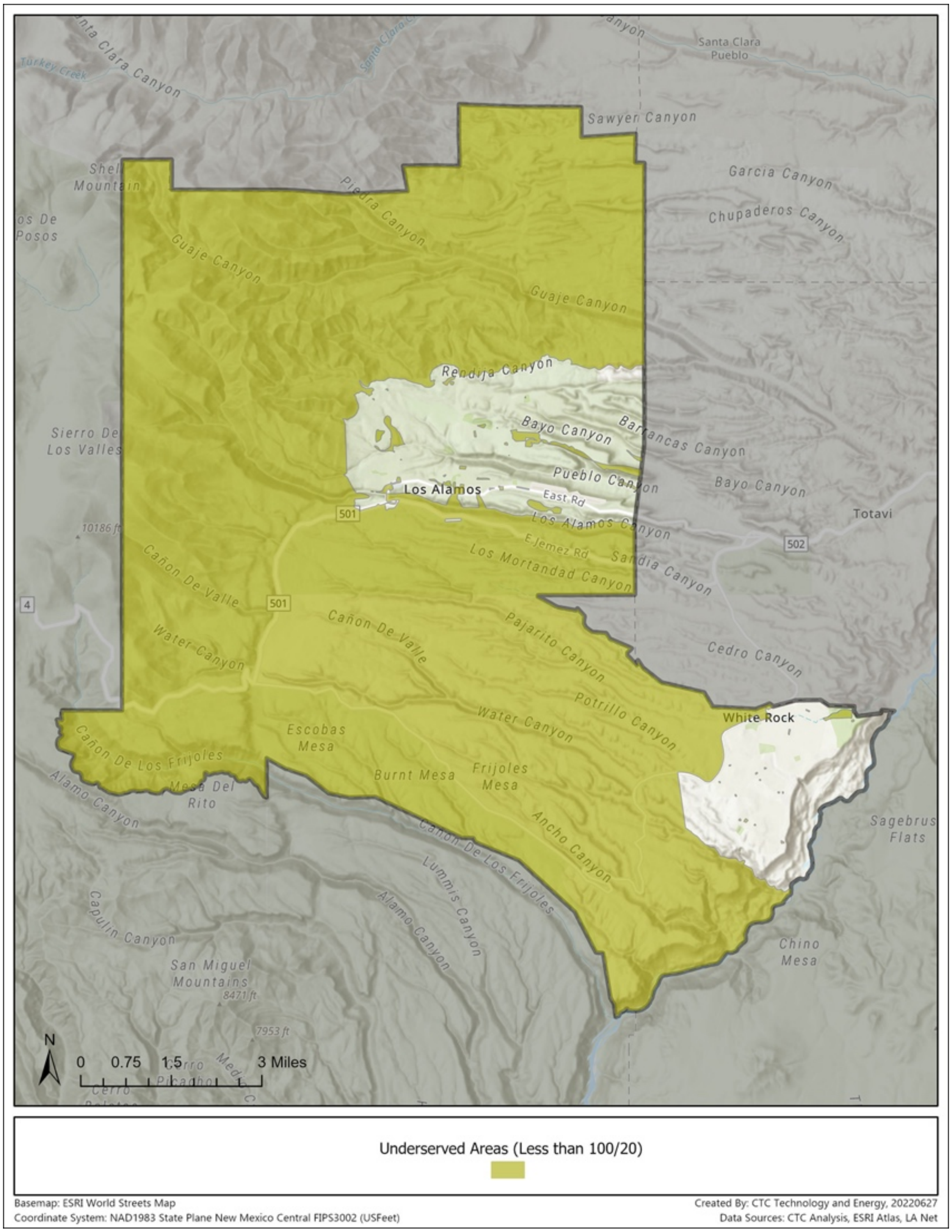
A larger portion of the County, shown in Figure 2, is underserved (i.e., residents do not have access to 100/20 Mbps service). These are the areas of the County not served by Comcast; no other providers offer 100/20 service outside Comcast's coverage area. Most of this area is sparsely populated. However, it does include some parts of the Townsite and White Rock.

Figure 2: Underserved areas (lacking 100/20 Mbps service)



1.3 Stakeholders and residents expressed dissatisfaction with available services and support for potential County action to promote broadband access

To gather input and data from the community about broadband needs, CTC conducted two discussions with stakeholders and residents, as well as a scientifically valid mail and online survey and an online speed test survey.

While almost all survey respondents (97 percent) have internet service, County stakeholders indicated that many are dissatisfied with the quality and speed of their service. The speed test survey supported these anecdotal reports: 88 percent of test results were below 100/20, and 36 percent were below the minimum broadband threshold of 25/3. Many households pay high prices for their service, with 38 percent of survey respondents paying $80 or more a month for unbundled internet service.

Discussion group participants viewed incumbent providers Comcast and CenturyLink as overly influential in the local market and stated that their service is inadequate, particularly in terms of available upload speeds. Stakeholders and residents generally supported the creation of an open-access network to encourage competition between providers, and were open to the County exploring a variety of business models for public-private partnerships to own and maintain such a network.

A significant portion of survey respondents also believed that the County should play a role in solving broadband issues, with 65 percent strongly agreeing and 20 percent agreeing that the County should ensure all residents have affordable and high-quality access to broadband.

1.4 A candidate fiber-to-the-premises network to serve the Townsite and White Rock would cost approximately $34 million

To support the County's goal of improving access to high-quality broadband services for residents and businesses, CTC developed three high-level models for a candidate FTTP network in Los Alamos County:

- **Model A (Townsite)** is a standalone design intended to reach all addresses within the Townsite of Los Alamos
- **Model B (White Rock)** is a standalone design intended to reach all addresses within the community of White Rock
- **Models A and B combined** would build out both Townsite and White Rock and connect the two areas via existing County-owned middle-mile fiber located between the areas

The total implementation costs of each model are summarized in Table 1, and are detailed in section Section 6.

Table 1: Estimated cost to build candidate FTTP networks

Description	Model A (Townsite)	Model B (White Rock)	Models A and B combined
Total fixed costs (with 20 percent contingency)[1]	$17,380,000	$9,120,000	$26,550,000
Total passings	7,198	2,816	10,014
Total fixed cost per passing	$2,400	$3,240	$2,650
Distribution network electronics, subscriber drops, and CPE (60 percent take-rate)	$5,523,000	$1,877,000	$7,400,000
Number of subscribers (60 percent take-rate)	4,318	1,690	6,008
Total implementation costs	$22,903,000	$10,997,000	$33,950,000
Cost per subscriber	$5,300	$6,500	$5,650

The candidate designs leverage existing infrastructure in the County where possible to lower the cost of construction. According to information provided by the County, the Townsite and White Rock have a total of 23 miles of available conduit and 9 miles of fiber; using that infrastructure would reduce the cost of the combined design by $3.1 million, which is factored into the costs above. Making use of existing middle-mile fiber between the two areas could save an additional $1.4 million in construction costs. The design also assumes that hubsites would be placed at County facilities to avoid the cost of purchasing or leasing property.

The FTTP design presented here shares some similarities with the design in the Crestino report, such as leveraging available infrastructure. However, advances in technology offer more flexibility in network architecture and available services. This report presents an independent design and assumptions.

1.5 Compared to a wireless solution, a fiber network would represent a more future-proof investment for the County

CTC and the County reviewed potential wireless technologies and concluded that an investment in a state-of-the-art fiber optic buildout would better serve the long-term interests of the County and its residents. Fixed wireless technologies have limitations on their ability to reliably ensure high speeds to every resident (see Appendix A: Technology comparative analysis), and a fixed wireless solution is unlikely to create significant competition for high-speed services against

[1] Fixed costs are the costs associated with building the backbone and distribution network; these costs do not include subscriber drops or distribution network electronics directly related to subscribers. The cost to build this part of the network will not change based on take-rate.

incumbent providers in the County. Deploying fixed wireless service at speeds of 100/20 or greater requires costly equipment for the provider, as well as expensive network equipment at customer premises.

Furthermore, a fixed wireless solution would not provide future-proof broadband infrastructure. Fixed wireless networks have a limited lifespan of five to seven years, while fiber optic cables have a usable life span of decades and are limited in speed only by network equipment that can be relatively easily upgraded.

1.6 Federal funding opportunities for broadband infrastructure in the County are likely limited

As the County is considered largely served by FCC data, it is unlikely to qualify for federal funding to build additional broadband infrastructure. Upcoming state and federal funding opportunities focus first and foremost on unserved locations (those without service of at least 25/3), and only secondarily on underserved locations (those with service less than 100/20). If funds remain to address some of the State's underserved locations, Los Alamos County is unlikely to be eligible or score sufficiently high on grant applications to secure funding since the County's primary concern is addressing the reliability and quality of available service, not coverage as defined by FCC maps.

1.7 The County could consider a range of business and partnership models to deploy an FTTP network

Los Alamos County represents a relatively attractive market for service providers. The Townsite and White Rock are relatively densely populated, and residents have higher education and income levels than in many comparable markets. A private partner may be willing provide some share of the capital needed to deploy an open-access network in return for partial County funding and/or future lease revenue.

Some operators will only consider networks that they own themselves, while others are open to managing a publicly owned infrastructure and taking on some of the risks of operations if they believe there is enough market potential to ensure sufficient revenue. A County procurement process intended to explore potential business models would need to be open to different arrangements in its specifications but could still emphasize that the County's preference is to own the network and engage private entities to operate it. Such a procurement process is designed to incentivize shifting risk from public to private entities through a competitive process, while still ensuring that the result fulfills the County's objectives of introducing competition and best-in-class services for residents and businesses.

2 Populated areas of Los Alamos County are widely served by cable broadband, but most residents do not have access to fiber service

Although cable service is widely available in Los Alamos County, fiber-based service is more limited. As a result, available service tiers in the County are inferior to the more robust service tiers available in fiber-rich markets. Most notably, available upload speeds are a fraction of what is available in fiber-rich markets. Furthermore, a lack of competitive pressure on the cable provider may lead to less investment in network upgrades, and less incentive to offer promotions or lower rates for customers in the County.

2.1 The County's population is largely served by broadband

For the purposes of this analysis, "unserved" means residential areas that do not have access to terrestrial fixed broadband at 25/3 Mbps speeds, and "underserved" means residential areas that do not have access to terrestrial fixed broadband at 100/20 Mbps speeds. These definitions mirror the standards set by the Infrastructure Investment and Jobs Act's historic federal investment in broadband infrastructure.[2]

While all residential areas were included in the analysis, it is important to consider the County's population distribution to understand patterns of network investment. Los Alamos County's population is tightly clustered around the Los Alamos Townsite and White Rock, with very sparse distribution in the more rural areas of the County (see Figure 3). The County's total population was estimated by the Census Bureau to be just over 19,000 in 2021, and the Townsite and White Rock were estimated to have just over 13,000 and just under 6,000 residents, respectively, in 2020.[3] While residences certainly exist in other parts of the County, the majority of the County's geographic area has a population density between 25 and 100 people per square mile.

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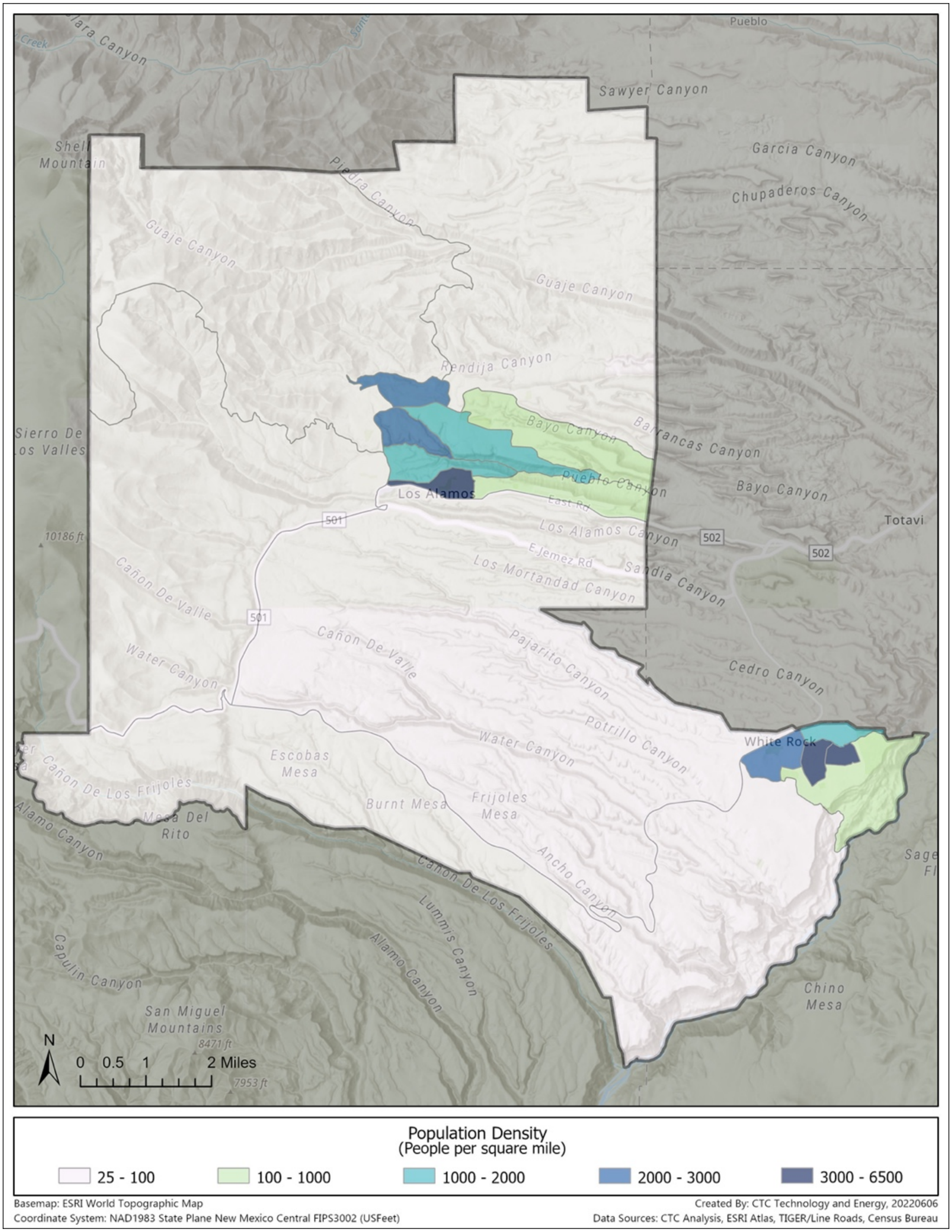
[2] "H.R. 3684 - Infrastructure Investment and Jobs Act," U.S. Congress, https://www.congress.gov/bill/117th-congress/house-bill/3684/text (accessed June 28, 2022).

[3] "Quick Facts: White Rock CDP, New Mexico; Los Alamos CDP, New Mexico; Los Alamos County, New Mexico," U.S. Census Bureau, https://www.census.gov/quickfacts/fact/table/whiterockcdpnewmexico,losalamoscdpnewmexico,losalamoscountynewmexico/PST045221 (accessed June 8, 2022).

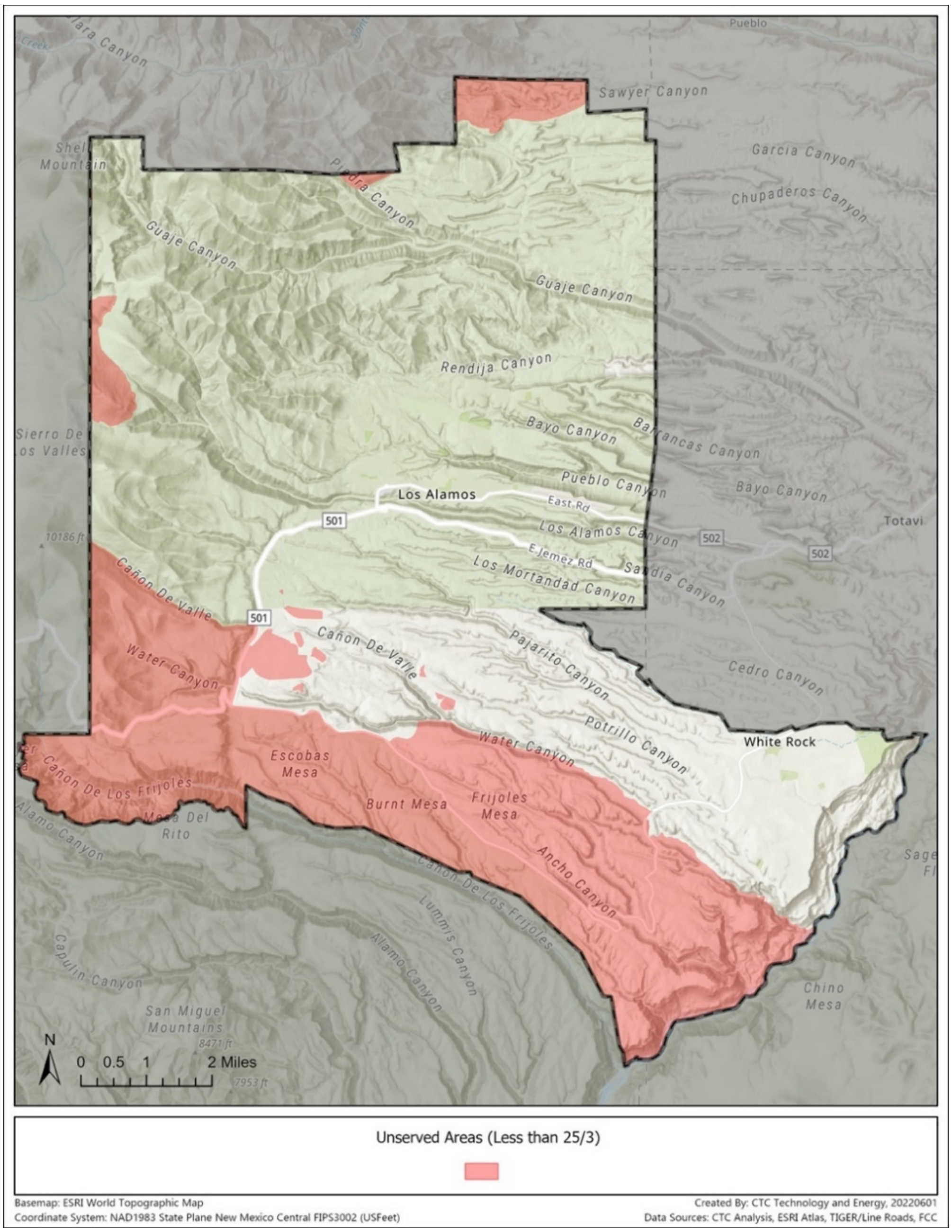
Figure 3: Population density in Los Alamos County



CTC identified the areas shown in Figure 4 as unserved. The County's unserved areas are primarily along the southern Route 4 corridor and just west of 501, as well as in a few pockets on the western and northern County borders. There are no unserved areas in the Townsite or White Rock.

Because all providers discussed in this report provide at least 25/3 Mbps services, these unserved areas are *fully* unserved by those ISPs. There are no cable, DSL, fixed wireless, or fiber services in these areas.

Figure 4: Areas unserved by 25/3 Mbps



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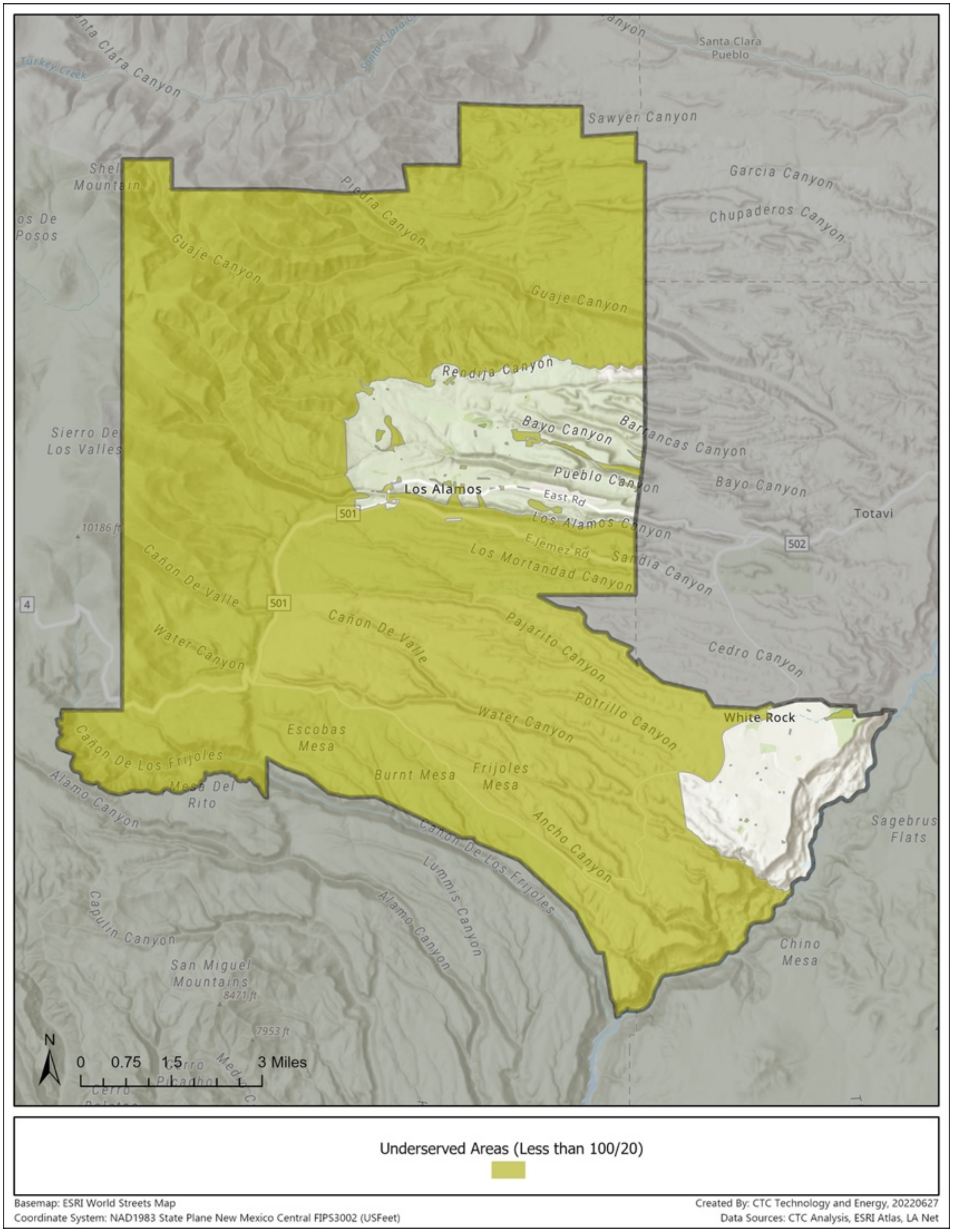
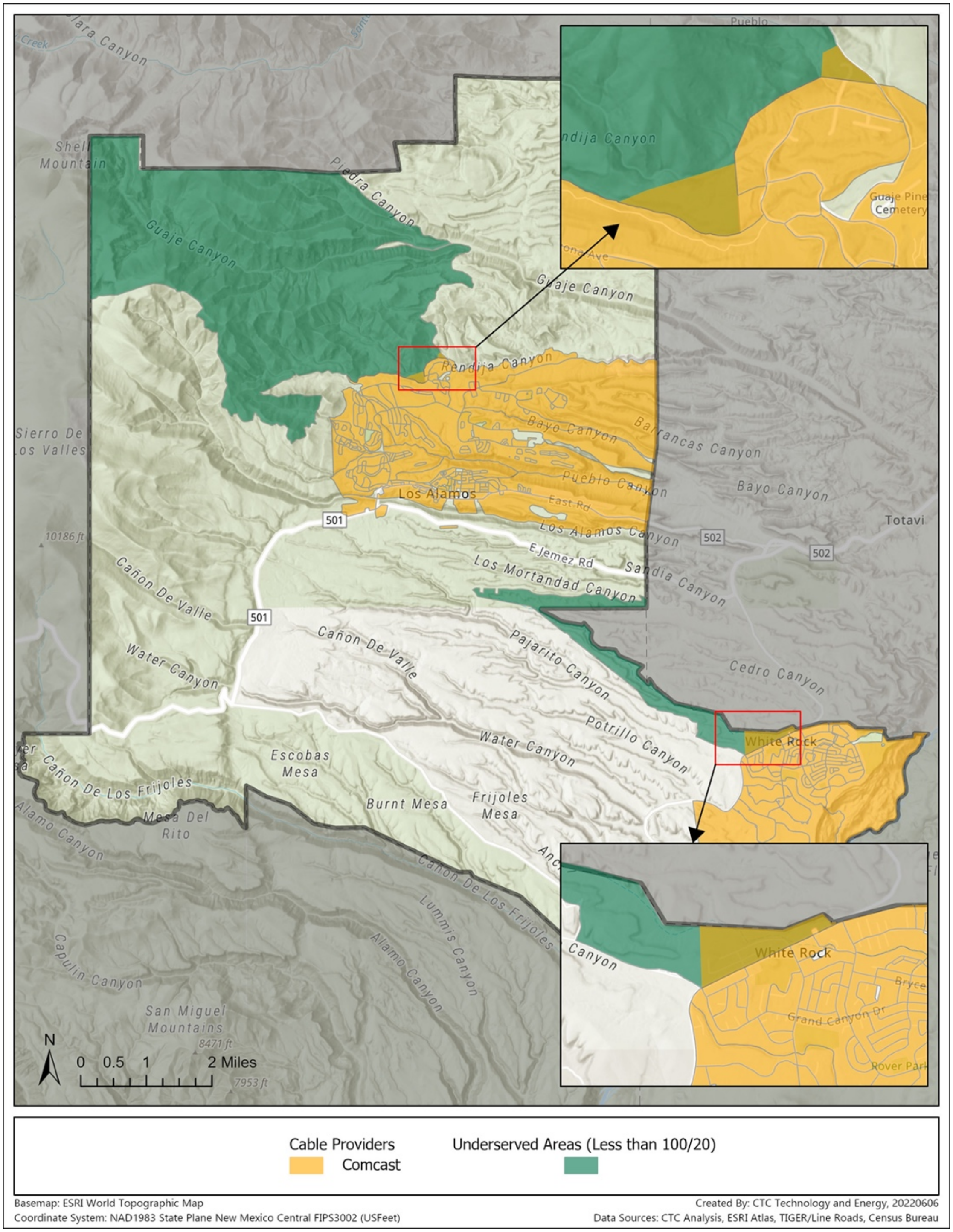
CTC identified the areas shown in Figure 5 as underserved. While these underserved areas also primarily encompass the most sparsely populated areas, they are more substantial than the unserved areas, and include some parts of the Townsite and White Rock.

Figure 5: Areas underserved by 100/20 Mbps



Comcast's service area overlaps slightly with two geographically large census blocks in the County, illustrated in Figure 6. This causes the FCC's Form 477 data to label the entirety of those blocks as served by 100/20 Mbps broadband. For the purposes of this report, CTC has labeled those blocks as underserved by 100/20 Mbps broadband, as shown in Figure 5 above.

Figure 6: Overlap between Comcast's service area and underserved areas in the County



2.2 Market assessment methods

This market assessment process involves several streams of data collection and analysis to form an understanding of where fiber, cable, digital subscriber line (DSL), and wireless networks exist; what services and pricing are available to residential and small business consumers; and what parts of the County are unserved and underserved by broadband based on Federal Communications Commission (FCC) data. Satellite providers were not assessed, as they do not provide consistent or adequate residential broadband speeds or service quality, and typically offer blanket availability.

CTC used the FCC's Form 477 data to analyze and map network footprints within Los Alamos County. Form 477 data are reported to the FCC by internet service providers (ISP) biannually and represent a best-case scenario; data are presented at the census block level, and the FCC considers a census block served by broadband if just one of the premises in the block could be served. The data thus tend to overestimate service availability, especially in less populated areas where one census block can span many square miles (such as in much of Los Alamos County).

FCC service data are also inconsistent for unpopulated areas such as parks or wildlife reserves. For example, if an ISP has extended service to a single visitor's center or building, FCC data may show a large unserved area around that location as being served. At times, a provider that reports service on Form 477 may not offer broadband services in the market at all.

CTC addresses these situations as they arise in the sections below. While the data's flaws are significant, Form 477 represents the most comprehensive national data set for broadband availability. CTC's desk and field survey work for the County will continue to refine this information and our understanding of broadband infrastructure and availability in the County.

CTC also researched websites of broadband providers operating in Los Alamos County and engaged in online and phone conversations with representatives of some ISPs to collect market data on residential broadband pricing and availability. The following providers in the Los Alamos County market were assessed:

Fiber providers:

- CenturyLink
- Los Alamos Net

Cable providers:

- Comcast

DSL providers:

- CenturyLink

Wireless providers:

- Black Mesa Wireless

- Los Alamos Net
- New Mexico Surf
- T-Mobile

CTC reviewed prices and service plans offered by all providers that made that information available, either on their websites or via information request. When possible, random residential and business addresses were selected in respective providers' service areas to determine available service and advertised pricing. Some other providers made non-address-specific plan information available directly on their websites. When these options were not available, service providers were contacted directly to obtain information about services and pricing. All research was conducted from April to June 2022; prices and plans are subject to change. The information presented here represents CTC's best understanding of the information presented by service providers at the time of research.

2.3 Fiber availability and pricing

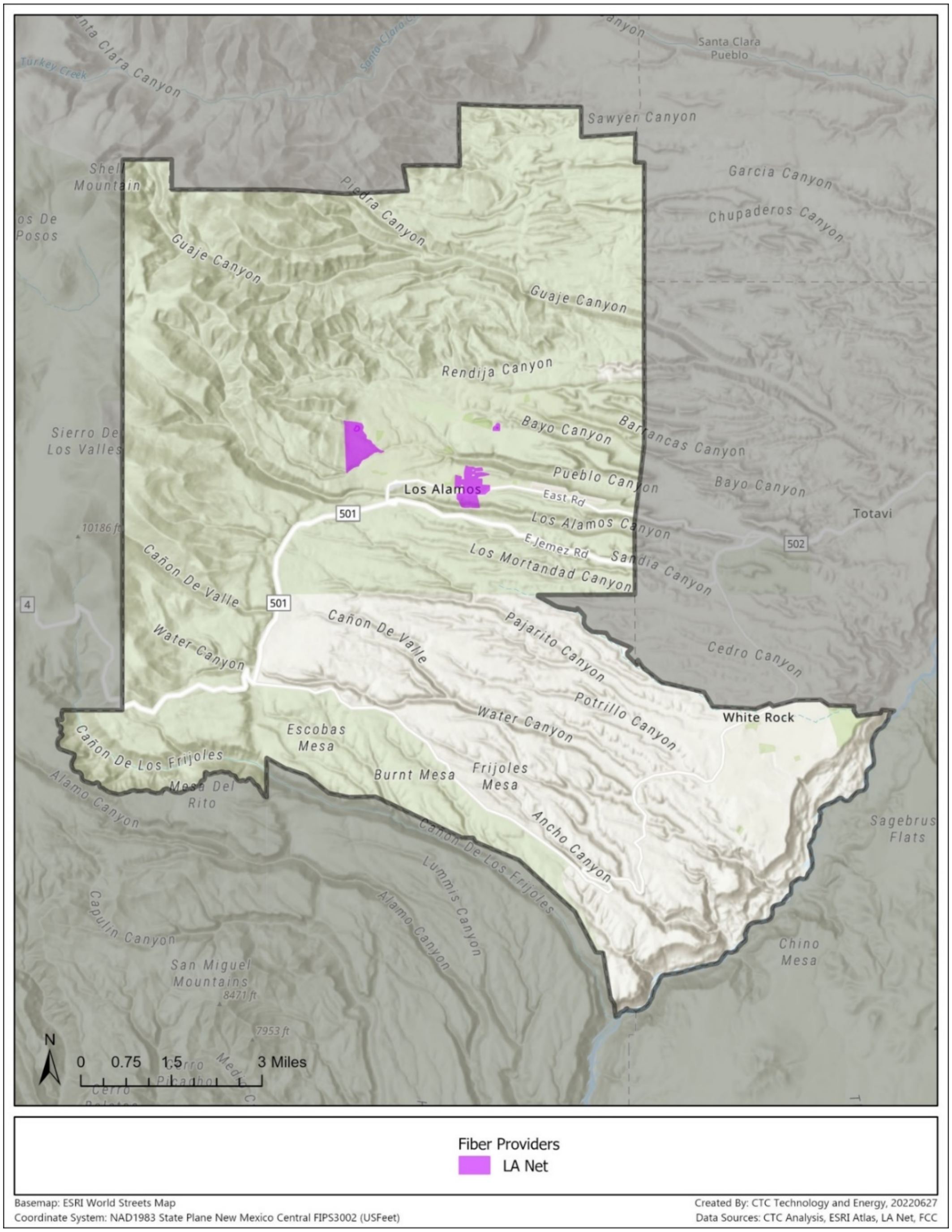
Fiber optic cables are the medium of choice for data transfer. They have enormous bandwidth capacity, which enables operators to offer symmetrical download and upload speeds. Once a premise is connected to fiber, there is no need for significant outside plant infrastructure investment for decades. This makes fiber networks significantly more scalable and future-proof than alternative infrastructures.

Los Alamos Net and CenturyLink were found to offer fiber services in Los Alamos County, though neither company's fiber services appeared on Form 477.

2.3.1 Los Alamos Net

Los Alamos Net does not report its services on Form 477, but CTC was able to determine through conversations with Los Alamos Net that the ISP offers fiber services in the downtown area of the Townsite, Quemazon, and Hawks Landing. CTC has approximated that service area in Figure 7.

Figure 7: Los Alamos Net's fiber service area in Los Alamos County



Los Alamos Net offers the residential fiber services described in Table 2.

Table 2: Residential fiber services offered by Los Alamos Net

Advertised download/upload speeds (Mbps)	Monthly non-promotional price[4]
10/10	$39.95
20/20	$49.95
50/50	$79.95
100/100	$99.95

In addition, Los Alamos Net offers the business services described in Table 3.

Table 3: Business fiber services offered by Los Alamos Net

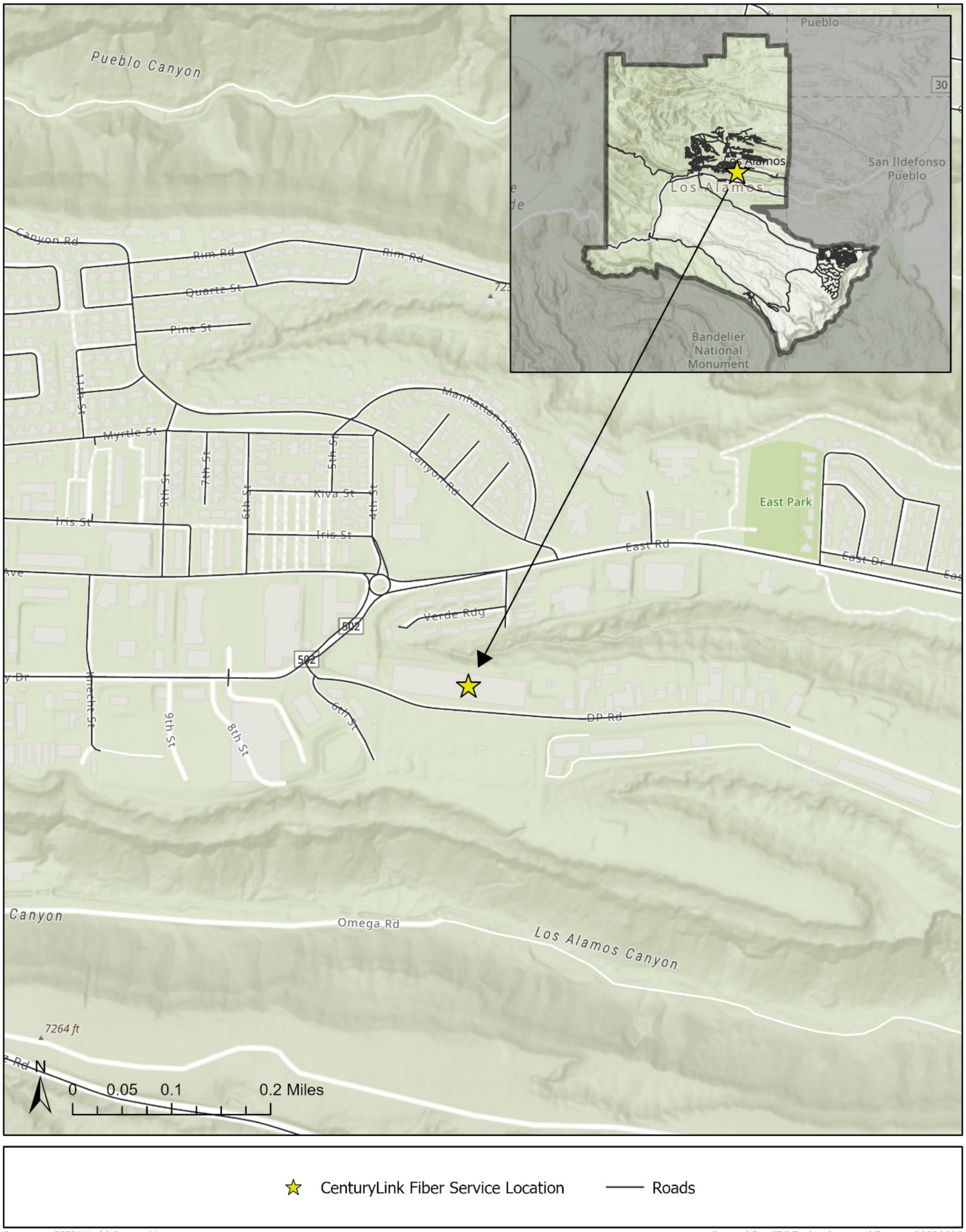
Advertised download/upload speeds (Mbps)	Monthly non-promotional price[5]
10/10	$49.95
20/20	$59.95
50/50	$89.95
100/100	$109.95

2.3.2 CenturyLink

While Lumen Technologies (doing business as CenturyLink in Los Alamos County) does not report fiber service in the most recent Form 477 data, the company does provide residential fiber broadband service to at least one recently constructed residential multi-dwelling unit in the Townsite (see Figure 8). The company is likely connecting most new developments in the area to fiber instead of copper, but the extent to which it may extend fiber to existing copper customers is currently unknown. Company management has recently announced plans to extend fiber to a large portion of its existing DSL customer base,[6] although the company has made no indication that it intends to build fiber to existing DSL customers in the Townsite at this time.

[4] Equipment or installation costs may be incurred.
[5] Equipment or installation costs may be incurred.
[6] Dianna Goovaerts, "Lumen targets 12m locations with Quantum Fiber push," Fierce Telecom, November 4, 2021, https://www.fiercetelecom.com/operators/lumen-targets-12m-locations-quantum-fiber-push (accessed May 30, 2021).

Figure 8: Location of newly constructed CenturyLink fiber



Basemap: ESRI World Streets Map
Coordinate System: NAD1983 State Plane New Mexico Central FIPS3002 (USFeet)

Created By: CTC Technology and Energy, 20220606
Data Sources: CTC Analysis, ESRI Atlas, Los Alamos County

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In the one location CTC could confirm fiber service is available, CenturyLink offered the service options and pricing described in Table 4.

Table 4: Residential fiber services offered by CenturyLink

Advertised download/upload speeds (Mbps)	Monthly price[7]
100/100	$50
500/500	$60
940/940	$70

2.4 Cable availability and pricing

Cable broadband technology is currently the primary means of providing broadband services to homes and businesses in most of the United States. Hybrid fiber-coaxial (HFC) networks were originally designed to provide video services, but had sufficient bandwidth to satisfy household and small business broadband needs in the early years of data communications. However, as demand for bandwidth has increased, coaxial networks have struggled to provide sufficient capacity (especially upload capacity) to satisfy current residential and small business usage patterns.

Cable providers are beginning to invest in network upgrades that will add additional download and upload capacity. However, companies have made it clear that they intend to target investments in upgrades to markets where they face the most competition,[8] potentially leaving markets where they are not at risk of losing market share to a fiber provider—like Los Alamos County—without improved service options for many years to come.

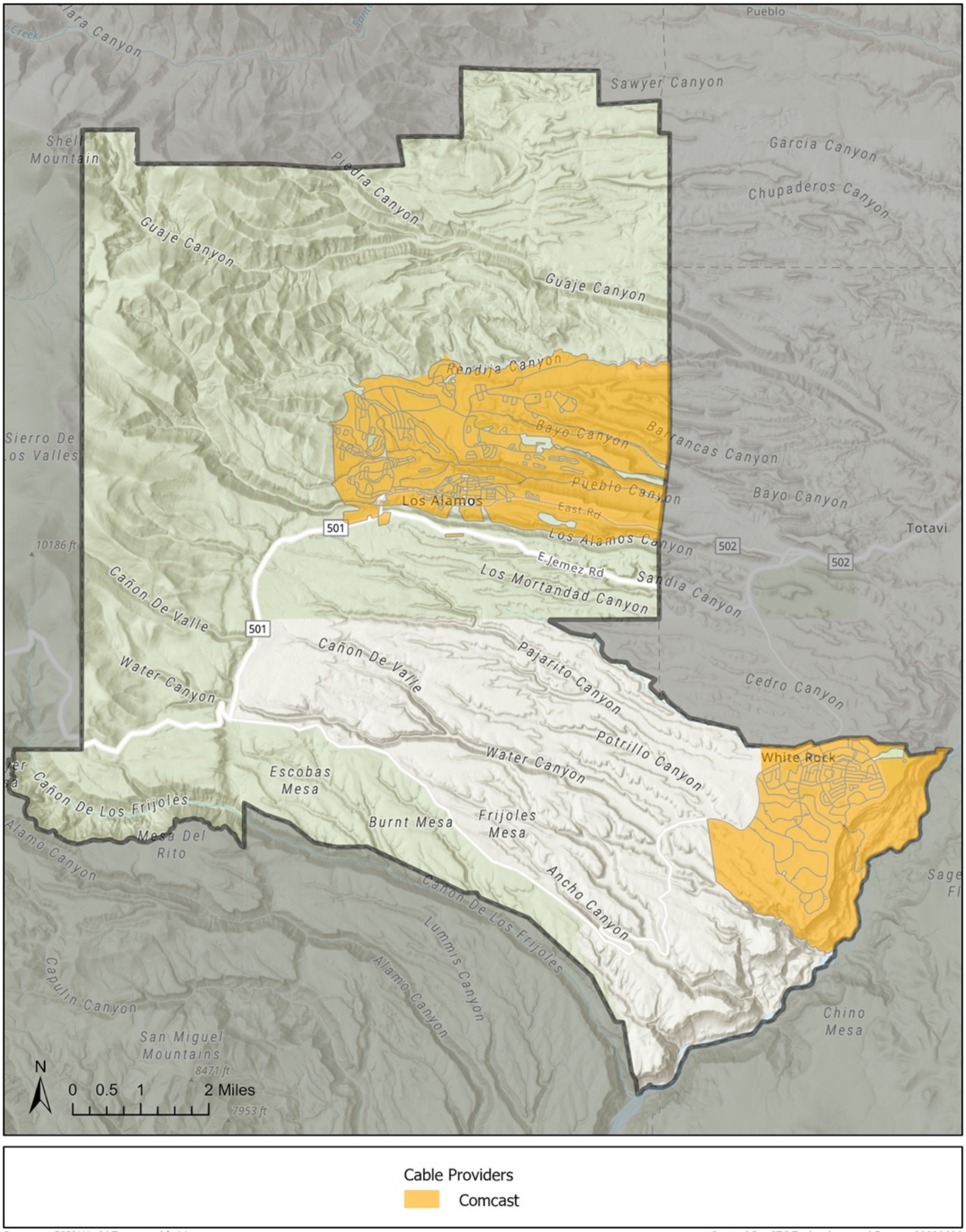
2.4.1 Comcast

Comcast is the sole cable provider in the County. Its reported service area surrounds much of the Townsite and White Rock, as shown in Figure 9.

[7] Equipment or installation costs may be incurred.

[8] Dianna Goovaerts, "Telco consultant says monolithic cable networks are a thing of the past," Fierce Telecom, April 15, 2022, https://www.fiercetelecom.com/telecom/telco-consultant-says-monolithic-cable-networks-are-thing-past (accessed May 31, 2022).

Figure 9: Comcast's cable service area in Los Alamos County



Basemap: ESRI World Topographic Map
Coordinate System: NAD1983 State Plane New Mexico Central FIPS3002 (USFeet)

Created By: CTC Technology and Energy, 20220606
Data Sources: CTC Analysis, ESRI Atlas, TIGER/Line Roads, Census Bureau

Comcast offers a wide range of residential cable products in Los Alamos County, as shown in Table 5. At each service level, Comcast offers a base price, which is shown in the table, as well as promotional prices that are available for limited periods of time and/or dependent on entering into a contract term agreement.

Table 5: Residential cable services offered by Comcast

Service	Advertised download/upload speeds (Mbps)	Monthly non-promotional price[9]
Connect	50/5	$60
Connect More	100/5	$70
Fast	300/10	$80
Superfast	600/15	$90
Ultrafast	900/20	$100
Gigabit	1,200/35	$110

Comcast's offerings also include Internet Essentials, a low-cost program for eligible households. Eligible low-income customers pay $9.95 per month for a wired internet connection with equipment included.[10] Internet Essentials also includes added benefits: customers can purchase a refurbished computer for $149.99,[11] and can access out-of-home Wi-Fi on Comcast's Wi-Fi hotspots across the country.[12]

In response to the Covid-19 pandemic, Comcast increased the program's connection speeds to the federal definition of broadband 25/3 Mbps—a welcome improvement.[13] Then, in early 2021, Comcast announced it was further increasing the speed to 50 Mbps download, 10 Mbps upload.[14] It now also offers "Internet Essentials Plus"—a 100 Mbps download, 10 Mbps upload product for

[9] $10 automatic payment and paperless billing discount available; lower prices advertised for first 12 months and/or with a one-year contract term; equipment or installation costs may be incurred.
[10] "Internet Essentials," Comcast, https://www.internetessentials.com/ (accessed June 21, 2022).
[11] "Low-Cost Computer," Comcast, https://www.internetessentials.com/low-cost-computer (accessed June 21, 2022).
[12] "Internet Essentials," Comcast, https://www.internetessentials.com/accessibility (accessed June 21, 2022).
[13] "Comcast Increases Access to and Speeds of Internet Essentials to Support Americans Through the Coronavirus Pandemic," Comcast, https://corporate.comcast.com/press/releases/internet-essentials-low-income-broadband-coronavirus-pandemic (accessed June 21, 2022).
[14] "Staying Connected During Coronavirus," Comcast, https://www.internetessentials.com/covid19 (accessed June 21, 2022).

$29.99, which is designed to match the new Affordable Connectivity Program subsidy of $30 toward broadband service.[15] Both Internet Essentials packages are described in Table 6.

Table 6: Comcast Internet Essentials services

Service	Advertised download/upload speeds (Mbps)	Monthly non-promotional price[16]
Internet Essentials	50/10	$9.95
Internet Essentials Plus	100/10	$29.95

Comcast also offers small business services, described in Table 7. While CTC was unable to obtain upload speed information from Comcast for its business services, it is likely that upload speeds for business services mirror those for residential services due to bandwidth constraints.

Table 7: Small business cable services offered by Comcast

Service	Advertised download/upload speeds (Mbps)	Monthly non-promotional price[17]
Starter Internet	35/-	$71.95
Business Internet 100	100/-	$119.99 per month for first 12 months, then $124.99 for months 13-24
Business Internet 200	200/-	$144.99 for first 12 months, then $159.99 for months 13-24
Business Internet 300	300/-	$174.99 for first 12 months, then $189.99 for months 13-24
Business Internet 600	600/-	$249.99 for first 12 months, then $264.99 for months 13-24
Business Internet 1 Gig	1,000/-	$349.99 for first 12 months, then $364.99 for months 13-24

2.5 DSL availability and pricing

During the last century, phone companies connected most homes and businesses in the U.S. to a strand of copper wire. Copper has a fraction of the bandwidth capacity of coaxial cable and

[15] "Apply for Internet Essentials or Internet Essentials Plus from Comcast," Comcast, https://www.xfinity.com/support/articles/comcast-broadband-opportunity-program (accessed June 21, 2022).
[16] Equipment included; eligibility requirements
[17] Two-year contract term required; $10 paperless billing and autopay discount available; equipment and installation costs may be incurred

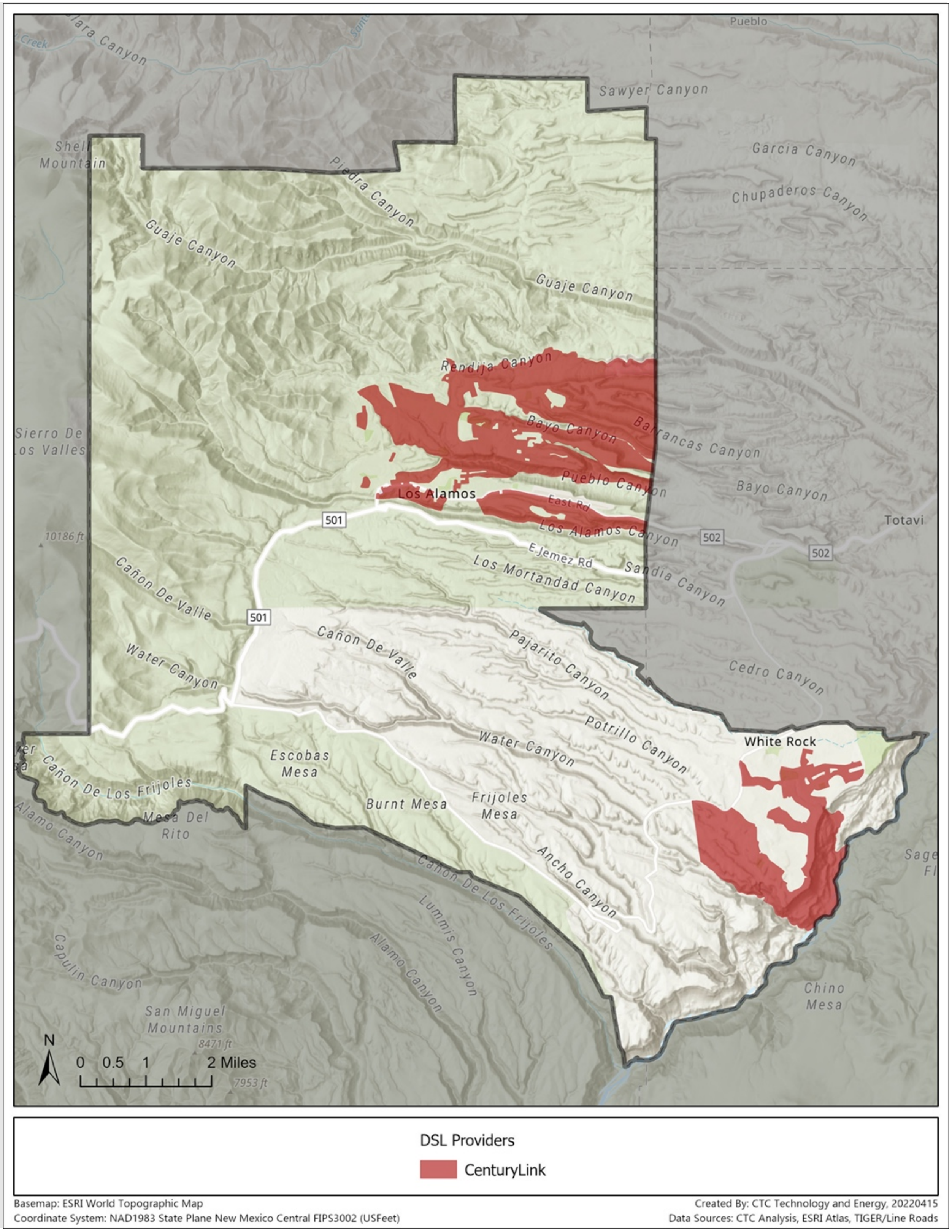
suffers from greater signal loss and interference—but because of its ubiquity, DSL technology over copper has been an important way for people to connect to the internet.

In some scenarios, DSL operators can offer speeds that fit the FCC's definition of broadband. However, while DSL has been an impressive retrofit of existing infrastructure, copper cable is reaching its physical limitations as a broadband medium and will not be able to meet future bandwidth needs.

2.5.1 CenturyLink

CenturyLink is the sole DSL provider in the County. CenturyLink reports a service area throughout some of the area in and north of the Townsite, as well as south of White Rock, as depicted in Figure 10. While Windstream also reported DSL services on Form 477, CTC determined that the ISP did not in fact serve the County. Windstream is therefore not included in this analysis.

Figure 10: CenturyLink's DSL service area in Los Alamos County



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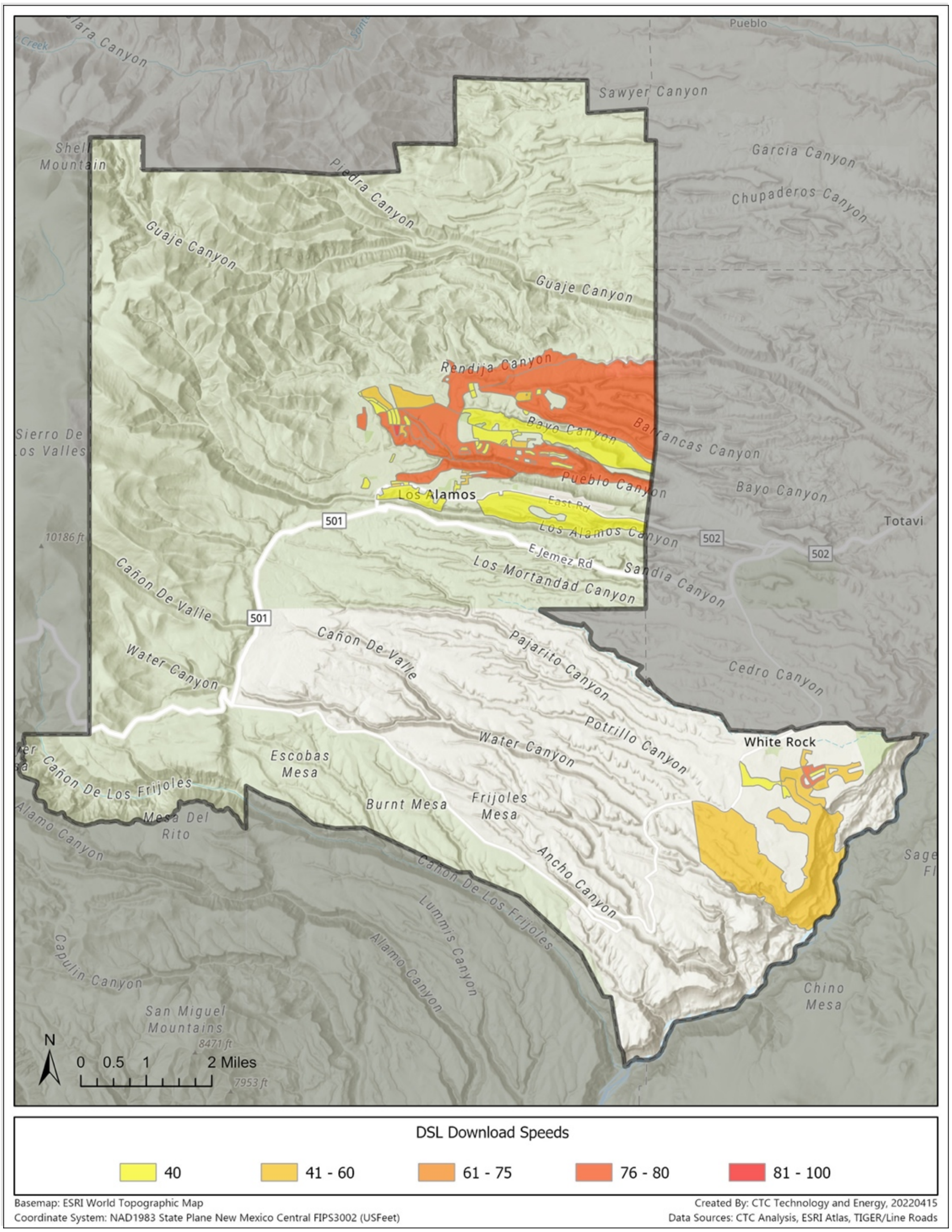
DSL speeds often vary by the location of the customer and their proximity to network plant. It is common for DSL providers to offer a single rate for the fastest service available at an address, despite available speeds varying significantly based on customer location—a practice known as "tier-flattening," in contrast to the multiple service tiers typically offered by cable or fiber providers. Figure 11 shows CenturyLink's reported available download speeds throughout the County in Mbps.

Figure 11: Reported DSL download speeds



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At multiple addresses in the County where CenturyLink reports residential services, advertised download speeds range from 3 to 40 Mbps, and advertised upload speeds range from 0.5 to 3 Mbps. Service was available at all addresses for $50 per month with additional router and modem costs, as shown in Table 8.

In markets where CenturyLink does not offer a fiber-based service, such as Los Alamos County (with the exception of at least one new construction residence, discussed in section 2.3.2), business DSL offerings typically mirror these residential services.

Table 8: DSL services offered by CenturyLink

Advertised download/upload speeds (Mbps)	Monthly non-promotional price[18]
3-40/0.5-3	$50

2.6 Wireless availability and pricing

Fixed wireless services generally use a combination of millimeter wave technologies, which require direct line-of-sight between an antenna and customer premise, and the same unlicensed spectrum bands as Wi-Fi, which does not have strong long-distance transmission qualities. For these reasons, the service areas claimed by fixed wireless providers should be considered best-case scenarios, and the availability of service to be installed at any given home would likely be evaluated on a premise-by-premise basis.

Separately, cellular wireless carriers have also been consistently increasing their data speeds with the rollout of faster and higher capacity technologies, such as “5G.” Over the past few years, they have provided data plans with speeds comparable to many residential customers’ internet service. Nationally, home 5G services are a relatively new addition to the residential broadband market, and it remains to be seen whether they will provide reliable, high-speed services that can compete with wireline services for everyday consumers.

New Mexico Surf reports fixed wireless coverage in nearly the entire County, while Black Mesa reports a small service area near White Rock. Los Alamos Net was found to also provide fixed wireless services in the Townsite and White Rock, and though they do not report these services on Form 477, CTC was able to approximate their wireless service area based on information provided by the ISP. Additionally, T-Mobile reports home cellular services in Los Alamos County, as discussed below.

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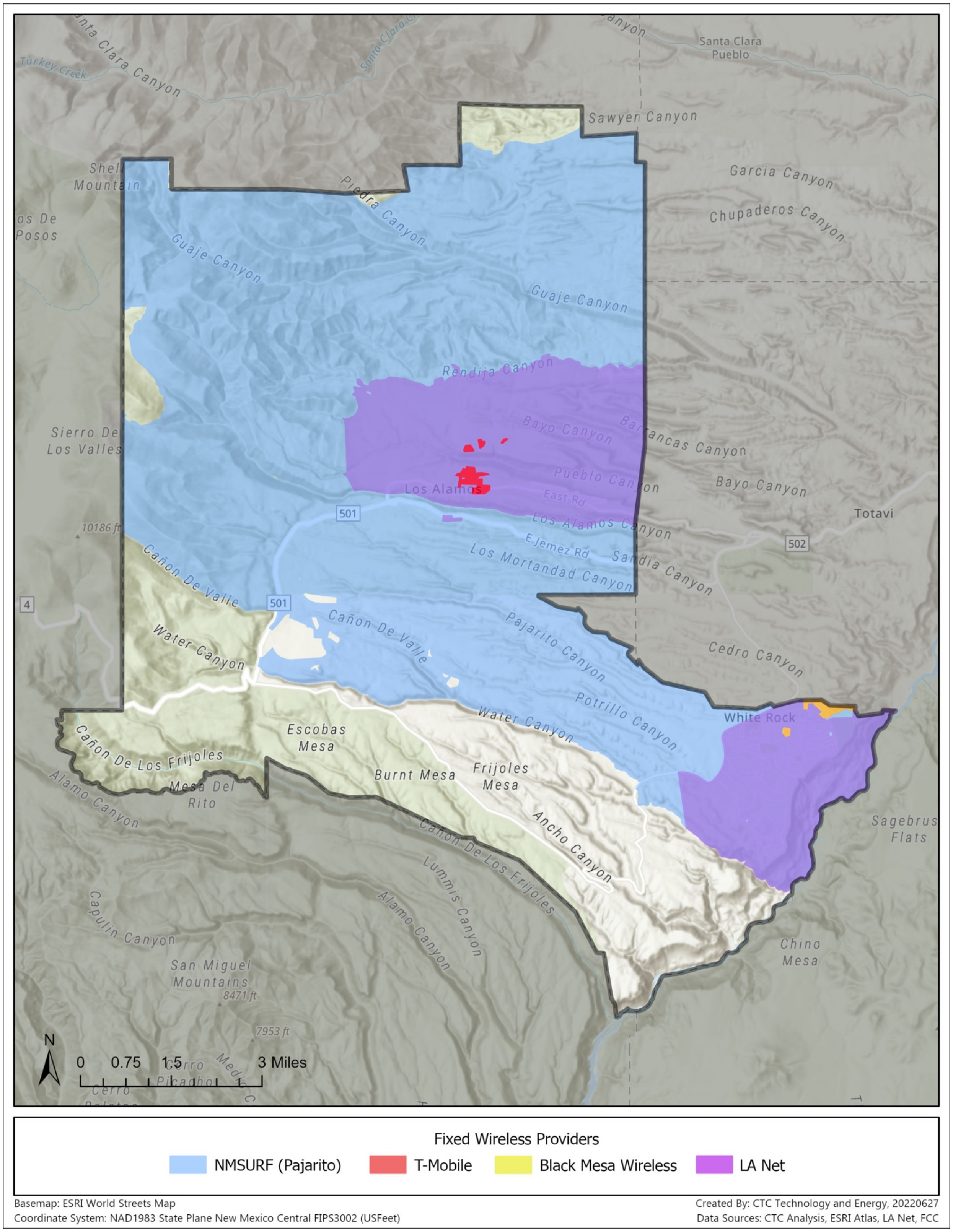
[18] Available speeds vary by address; equipment and installation costs may be incurred.

Figure 12: Residential wireless providers in Los Alamos County



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2.6.1 Los Alamos Net

Los Alamos Net's fixed wireless offerings mirror its fiber offerings. The residential plans are described in Table 9 and the business plans are described in Table 10.

Table 9: Residential fixed wireless services offered by Los Alamos Net

Advertised download/upload speeds (Mbps)	Monthly non-promotional price[19]
10/10	$39.95
20/20	$49.95
50/50	$79.95
100/100	$99.95

Table 10: Business fixed wireless services offered by Los Alamos Net

Advertised download/upload speeds (Mbps)	Monthly non-promotional price[20]
10/10	$49.95
20/20	$59.95
50/50	$89.95
100/100	$109.95

2.6.2 New Mexico Surf

New Mexico Surf offers five wireless services, each available to both residential and business customers. These services are described in Table 11.

[19] Equipment or installation costs may be incurred.
[20] Equipment or installation costs may be incurred.

Table 11: Wireless services offered by New Mexico Surf

Service	Advertised download/upload speeds (Mbps)	Monthly non-promotional price[21]
Light Wave	10/2	$39.99
Heavy Wave	15/5	$49.99
Massive Wave	25/7	$59.99
Extreme Wave	50/10	$69.99
Tsunami Wave	100/25	$79.99

2.6.3 T-Mobile

T-Mobile offers a single home internet product for a flat rate, described in Table 12. Customer speeds will vary based on network availability at a specific address, among other factors.

Table 12: Residential wireless services offered by T-Mobile

Service	Advertised download/upload speeds (Mbps)	Monthly non-promotional price[22]
T-Mobile Home Internet	For 4G network: 30-110/6-23 For 5G network: 33-182/8-25	$55

In addition, T-Mobile offers a Small Business Internet service, which largely follows the same structure as Home Internet. This product is described in Table 13.

Table 13: Small business wireless services offered by T-Mobile

Service	Advertised download/upload speeds (Mbps)	Monthly non-promotional price[23]
T-Mobile Small Business Internet	33-182/6-23	$55

[21] Two-year contract terms are required for standard pricing; monthly and one-year terms may be available; equipment and installation costs may be incurred
[22] $5 autopay discount available; equipment included
[23] $5 autopay discount available; equipment included

2.6.4 Black Mesa

Black Mesa reports four residential wireless service options, described in Table 14. The fastest speed tier is described by the company as "available in select locations subject to site survey and on-site testing."[24]

Table 14: Residential wireless services offered by Black Mesa

Advertised download/upload speeds (Mbps)	Monthly non-promotional price[25]
5/5	$55
15/7	$70
25/12	$105
40/20	$150

2.7 Federal infrastructure funds to support future services were awarded to satellite providers

While the maps above offer an approximation of existing residential broadband availability, infrastructure award data can offer insight into where some providers are planning future infrastructure builds. CTC analyzed FCC data to determine where in the County ISPs have received funding for new infrastructure projects. Two infrastructure funding programs were analyzed: the FCC's Connect America Fund Phase II (CAF II) Auction and the FCC's Rural Digital Opportunity Fund (RDOF) Phase I Auction.

While each auction had an award recipient in the County, none bid to offer terrestrial services. In the CAF II auction, Viasat placed a winning bid to provide 25/3 Mbps satellite service along Route 4 from the Ancho Canyon through the Frijoles Mesa, as seen in Figure 13. In the RDOF auction, SpaceX placed winning bids to provide 100/20 Mbps satellite service primarily along the eastern County border from White Rock to the Los Mortandad Canyon, as seen in Figure 14. The FCC has since rejected certification of SpaceX's RDOF winnings, skeptical that it can deliver the service it promised. Regardless, neither project would bring new terrestrial infrastructure investment to the County.

[24] https://www.blackmesawireless.com/plans (accessed June 14, 2022).

[25] Equipment and installation costs may be incurred.

Figure 13: Awarded CAF II auction areas

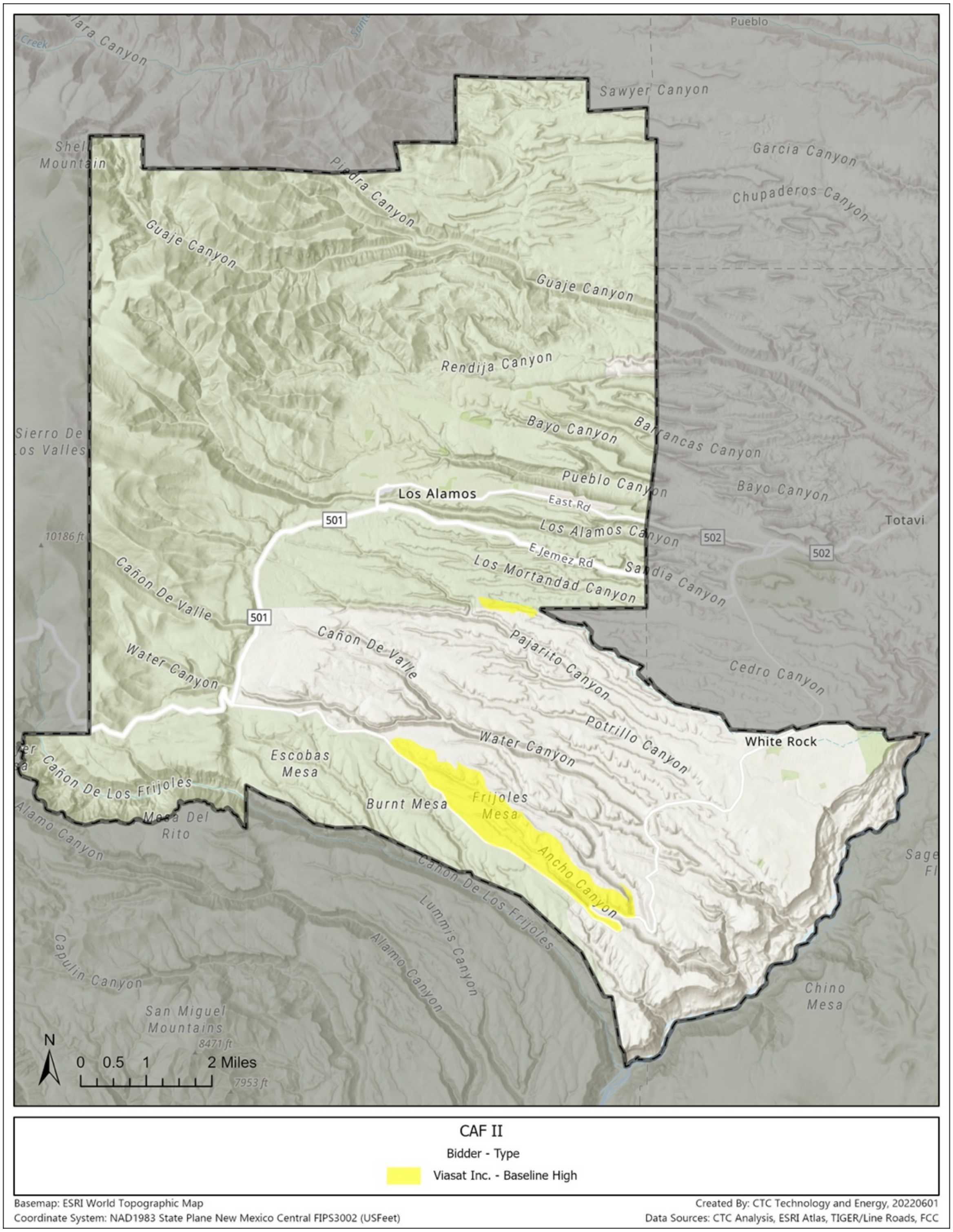

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Figure 14: Awarded RDOF auction areas

RDOF

Provider - Tier - Latency

Space Exploration Technologies Corp. - Above Baseline - Low

Basemap: ESRI World Topographic Map
Coordinate System: NAD1983 State Plane New Mexico Central FIPS3002 (USFeet)

Created By: CTC Technology and Energy, 20220601
Data Sources: CTC Analysis, ESRI Atlas, TIGER/Line Roads, FCC

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3 Residents in served areas do not uniformly adopt broadband services

Assessing Census Bureau demographic data can assist in understanding what parts of the County may be affected by a lack of access to broadband, low rates of broadband adoption, or a combination of the two.

Currently available data from 2020 show that investment in wireline broadband infrastructure has largely occurred in the most densely populated areas in the County; however, census data also show that not all households in those areas subscribe to broadband services.

Median household income and percentages of the population below poverty level are mapped by census tract in Figure 15 and Figure 16, respectively. The median household income is the lowest, and the percentage of the population below the poverty level is the highest, in the large census tract that includes the Townsite and extends to the western part of White Rock. Accordingly, broadband affordability may be a concern in these population centers.

Figure 15: Median household income

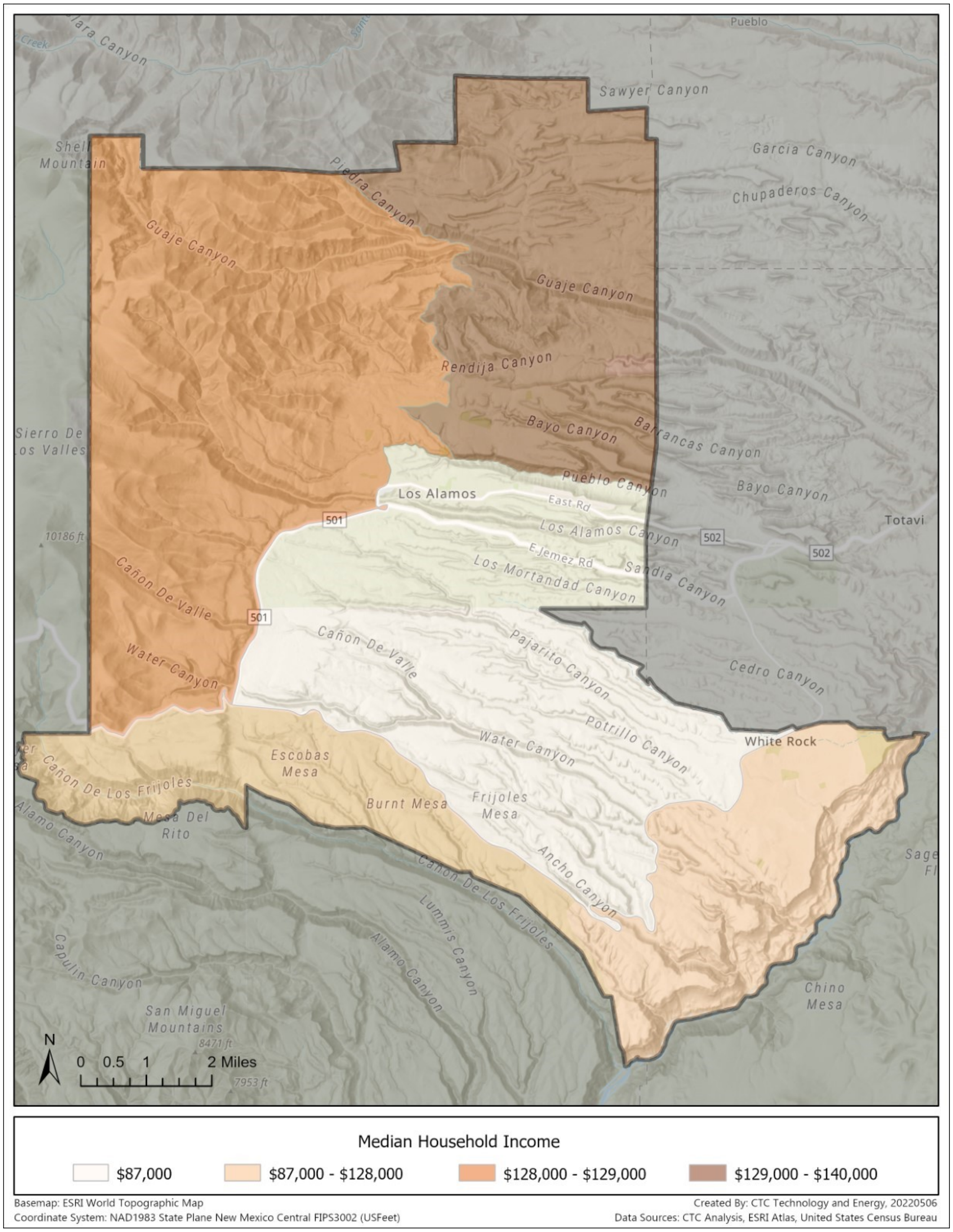
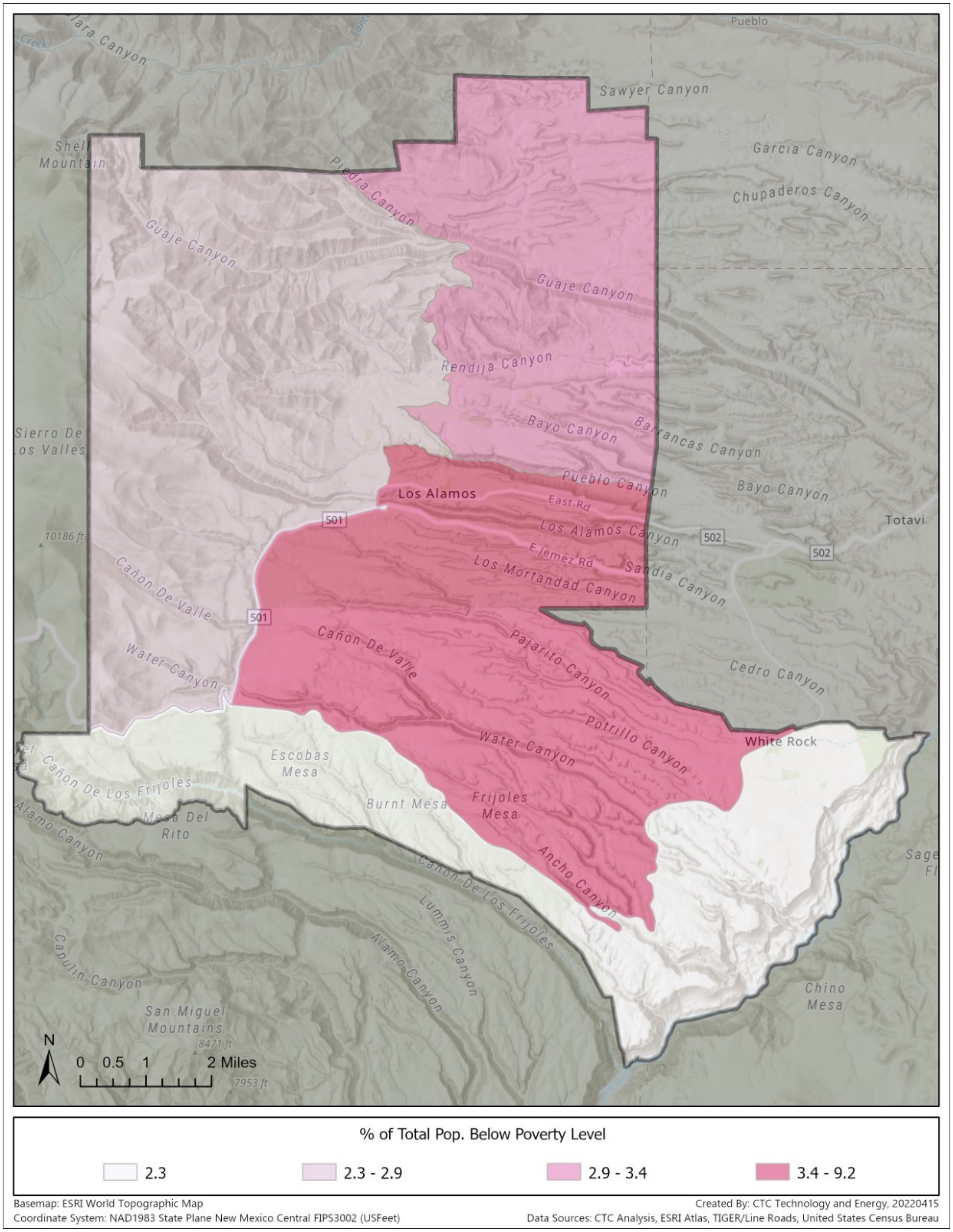


Figure 16: Percentage of population below poverty level



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Census Bureau data were used to map the proportion of households without internet access and without a computer, both reported at the census block group level. The percentage of households that report they do not have internet access at home (Figure 17) is higher in much of the Townsite and White Rock areas than the less dense areas in the southern and northwestern parts of the County.

The lower levels of internet adoption in and surrounding the Townsite and White Rock—areas found in CTC's analysis to be served by higher speeds and more providers than the less dense areas of the County—as well as lower levels of home computer ownership (depicted in Figure 18) suggest that affordability, reliability, or other service concerns may be lowering internet adoption.

However, comparing Figure 17 to the map of population density in Figure 3 shows that large portions of geographic areas shown to have low levels of internet adoption are not populated. Due to the large size of census tracts in Los Alamos County, data from a few households in the outskirts of populated areas has likely been reported for the entirety of a census tract. The County should attempt to identify specific areas where internet adoption is low, which could be a focus for programmatic efforts to address the affordability of service for these residents.

Figure 17: Percentage of households without internet access

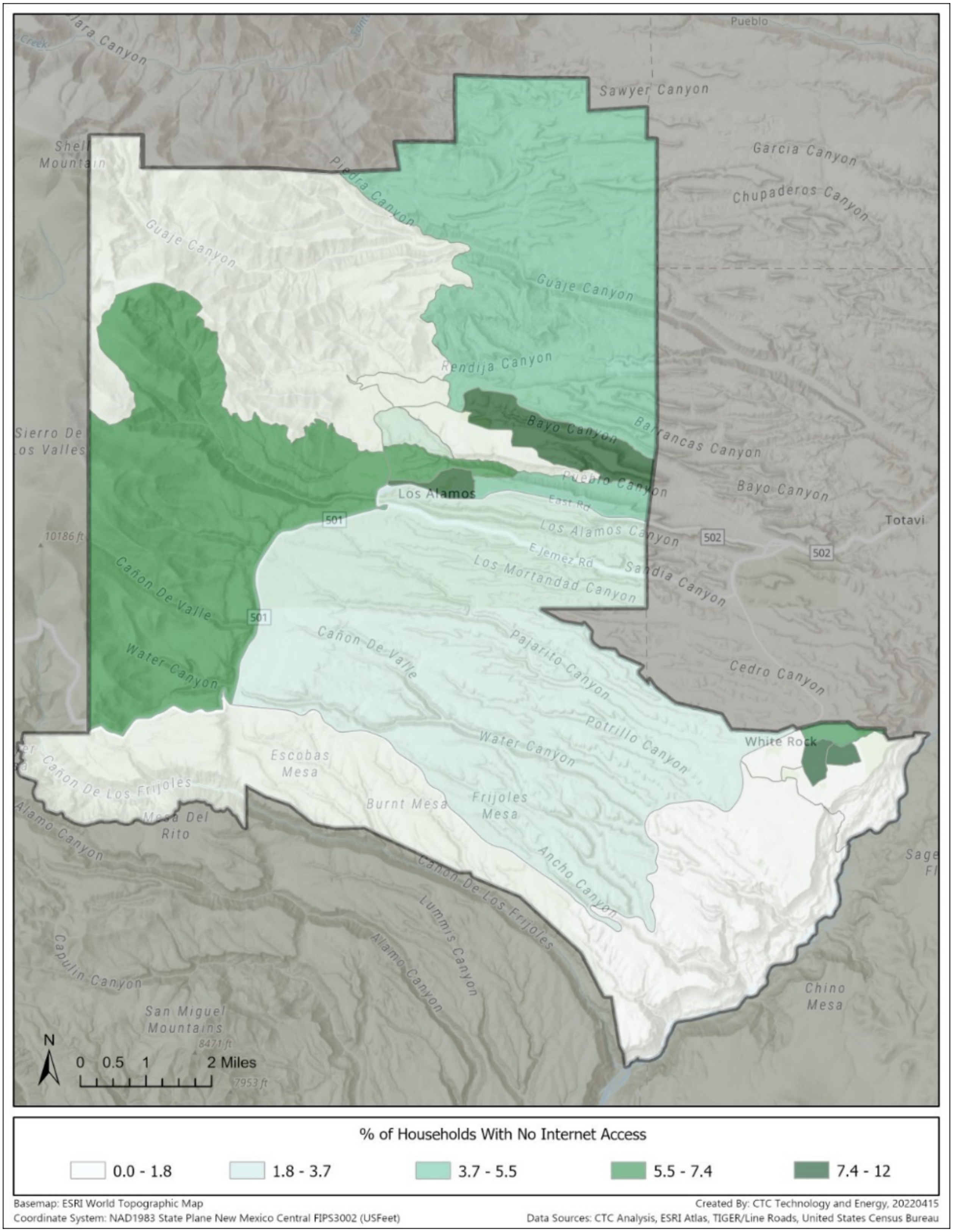
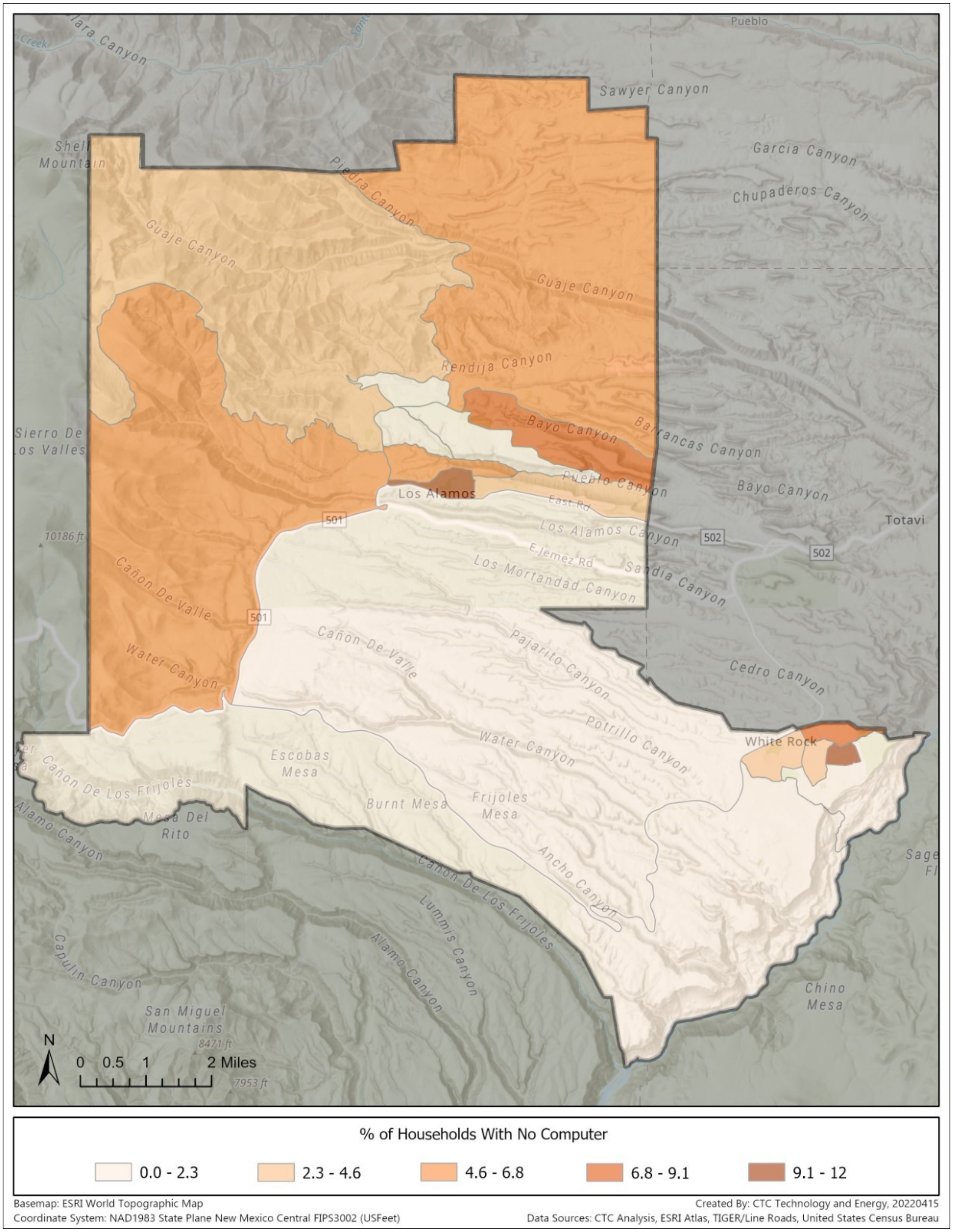


Figure 18: Percentage of households without a computer



4 Stakeholders expressed interest in the creation of an open-access network to support competition between providers

To inform the strategic planning process, CTC engaged stakeholders and residents to gather feedback and data on their needs and challenges around broadband. The project team held two workshops—a Town Hall discussion for stakeholders and a community broadband forum that was open to both stakeholders and residents—in October 2022.

4.1 Key findings

The following are high-level insights gained from the Town Hall and the community broadband forum:

- Stakeholders voiced concerns about lack of redundancy of middle-mile fiber in the County.
- Participants viewed incumbents Comcast and CenturyLink as too influential in the market and stated that the service they provide is inadequate, particularly in terms of upload speeds.
- Since the County is considered served according to FCC data, it is unlikely that it will qualify for federal funding for additional infrastructure. However, participants stated that the creation of an open access network would create more competition and improve quality of service.
- Participants were in favor of policies that allow for new conduit to be built when the Transportation Board is completing repairs.
- Stakeholders also expressed that fiber built by the County since the Crestino report was issued in 2013 should be leveraged whenever possible.
- Stakeholders were open to the County exploring different business models for public-private partnerships for ownership and maintenance of an open access network.

4.2 Stakeholder feedback

Two hybrid sessions (both in person with a virtual component) were held on October 19, 2022 to gather feedback from stakeholders and residents of Los Alamos County. Participants were given an overview of the broadband strategic plan process and were asked their opinions on broadband service and reliability in the County. They were also informed about the resident survey and speed test survey conducted by CTC and were asked to publicize both to their respective networks.

4.2.1 Town Hall

Eight participants were included in the Town Hall discussion in addition to County and CTC staff:

- Alicia Griego: Staff, Los Alamos Network
- Michael Holtzclaw: Chancellor, University of New Mexico Los Alamos (UNM-LA)
- Pam King: Senior Vice President, Century Bank
- Lauren McDaniel: Executive Director, Los Alamos Commerce & Development Corporation
- Tadeusz Raven: Founder, Attack Research
- Allan Saenz: Owner, Los Alamos Network
- Dan Ungerleider: Economic Development Administrator, Los Alamos County
- Sal Zapien: Director of Technology, Los Alamos Public Schools

A few major themes were discussed in the Town Hall, as described below.

4.2.1.1 Middle-mile concerns

Though the development of the County's broadband plan is focused on last-mile infrastructure, some participants raised concerns about a lack of redundancy for middle-mile infrastructure and expressed the need for a second fiber optic line. A participant mentioned that Redi-Net had attempted to construct a second middle-mile fiber optic line and was unable to complete the project, but had installed conduits that are not in use.

4.2.1.2 Incumbent performance and influence

A few participants expressed that CenturyLink and Comcast have a significant amount of influence on the market in Los Alamos County. One person referred to the County as "a victim to CenturyLink" because it depends on the incumbent to provide fiber to reach new County facilities. Some also stated that incumbents would fight to prevent the addition of a second fiber optic middle-mile line.

Participants also claimed that the cable service from Comcast was inadequate for small businesses; one participant stated that download speeds of up to 1.2 Gbps are available, but upload speeds will not exceed 50 Mbps. Though much of the County is covered by DSL service, it is considered unusable for small business.

4.2.1.3 Desire for open access

Several participants discussed creating an open-access network to support increased competition between ISPs. Participants concurred that multiple providers should be able to access the network to offer greater choice to consumers and potentially more reliable service overall.

4.2.1.4 Funding possibilities

The group recognized that there is a low likelihood of gaining federal funding for additional infrastructure given that the County is considered largely served by federal standards. Participants discussed the possibility of partnering with neighboring counties and communities on solutions beyond County borders. There was also discussion about cost-sharing for new infrastructure; if the County invests a certain percentage, the State may also be likely to contribute funding.

4.2.2 Community broadband forum

The second session was opened to community members as well as industry stakeholders. Fourteen people attended this session in addition to County and CTC staff:

- Gerald Bakkar: General Manager, Redi-Net
- Ann and Richard Browning: Residents
- Andy Fraser: Resident
- Marcus Halen: Resident of White Rock
- Akana Peck: Resident
- Allan Saenz: Owner, Los Alamos Network
- Eduardo Santiago: Resident of Barranca
- Gary Stradling: Candidate for County Council
- Roselle Wright: Resident of Barranca Mesa
- Sal Zapien: Director of Technology, Los Alamos Public Schools
- Other residents (no last names given): Jason, Jim, George, Ruth

The questions for this group focused primarily on infrastructure in the County and potential ownership models, and the following main themes were discussed.

4.2.2.1 Conduit and fiber

One participant asked about adding conduit each time the Transportation Board completed any repairs. The New Mexico Department of Transportation has recently implemented new policies to install new conduit whenever feasible, but rocky terrain in the area can make the implementation process problematic.

County representatives also displayed a map of available County-owned fiber and discussed the existence of lines with 144 and 288 strands. Not all these strands are available for last-mile distribution. Another participant asked about last-mile distribution options from each node on the fiber network.

One participant also asked why the recommendations from the Crestino report were not implemented. County officials responded that the report recommended an approximately $60 million build-out, which was not feasible at the time. Participants were informed that this report is intended to build on the conclusions from the Crestino report but also take into consideration the new assets available to determine the most cost-effective and efficient solution going forward.

4.2.2.2 Public-private partnership models

Different business models for owning and operating a fiber network were also discussed in this forum. One participant expressed an interest in County-owned fiber to ensure that the current monopoly situation is not perpetuated. If the County chose to own the network, it could contract with a private ISP for operations and maintenance or manage the network itself.

When asked if the County was seeking a single entity for partnership through a procurement process, representatives stated that the County Council would decide the path forward. It would be unlikely that the County would engage multiple providers, but all options are on the table for the council to consider.

5 Though most County residents are served, speeds can be lower than promised and residents feel that the County has a responsibility to ensure broadband access

CTC also conducted a statistically valid mail and online survey of County households that received 771 responses, as well as an online speed test survey. The following sections describe the survey methodology and results.

5.1 Key findings

The survey revealed the following key insights:

- The County is comprehensively served (97 percent of respondents have internet service); Comcast serves about two-thirds of the respondents.
- Speed test survey results supported anecdotal information from County stakeholders that services from incumbent providers are performing below expectations. 88 percent of results were below 100/20, and 36 percent were below 25/3—which suggests that some subscribers could be effectively unserved.
- County residents are paying high prices for internet service (38 percent pay $80 or more a month for unbundled internet service), but they feel they are overpaying.
- A significant majority (82 percent) reported that two or more devices are used in the household simultaneously, which could contribute to degradation of speed for those who subscribe to lower speed tiers or have unreliable internet service.
- About a tenth of respondents (11 percent) said they use their home internet service to run a business. The most common use cases are for entertainment, shopping and online banking.
- Internet skills are strong among respondents, with a large majority feeling comfortable in accomplishing a number of online tasks. Respondents did not indicate great interest in training programs or skill building. 22 percent strongly agreed or agreed that they would like to become more confident in their skills and 16 percent stated that they would be interested in a free or inexpensive training class.
- A high proportion of respondents felt that the County is responsible for solving broadband issues. 75 percent strongly agreed that the County should ensure that all students have affordable and high-quality access to broadband, and 65 percent strongly agreed that all residents should have affordable and high-quality access.

5.2 Survey methodology

Paper surveys were sent to 4,000 addresses; in addition, an online version was promoted by the County. The survey queried residents about their internet usage, their providers, pricing, reasons for online usage, computer skills and knowledge, and their opinions on broadband priorities for the County. A total of 771 responses were collected from an estimated 7,895 households. The project team also conducted a separate speed test survey of residents; the paper survey had a participant code for respondents to enter into the speed test survey so that the two data sets could be correlated.

The margin of error is a common measure of statistical validity or accuracy. The margin of error for aggregate results at the 95 percent confidence level for 771 responses is ±3.4 percent. That is, for questions with valid responses from all survey respondents, one would be 95 percent confident (19 times in 20) that the survey responses lie within ±3.4 percent of the target population as a whole. The margin of error is larger for various subgroups.

5.3 Survey results

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

5.3.1 Home internet service, providers and pricing

Nearly all of residents who responded to the survey (97 percent) subscribe to home internet service, as shown in Figure 19. Over half of respondents (66 percent) use Comcast, 17 percent use CenturyLink/Lumen, and 14 percent use Los Alamos Net. Figure 20 shows all service providers reported in the county.

Figure 19: Respondents who have home internet service

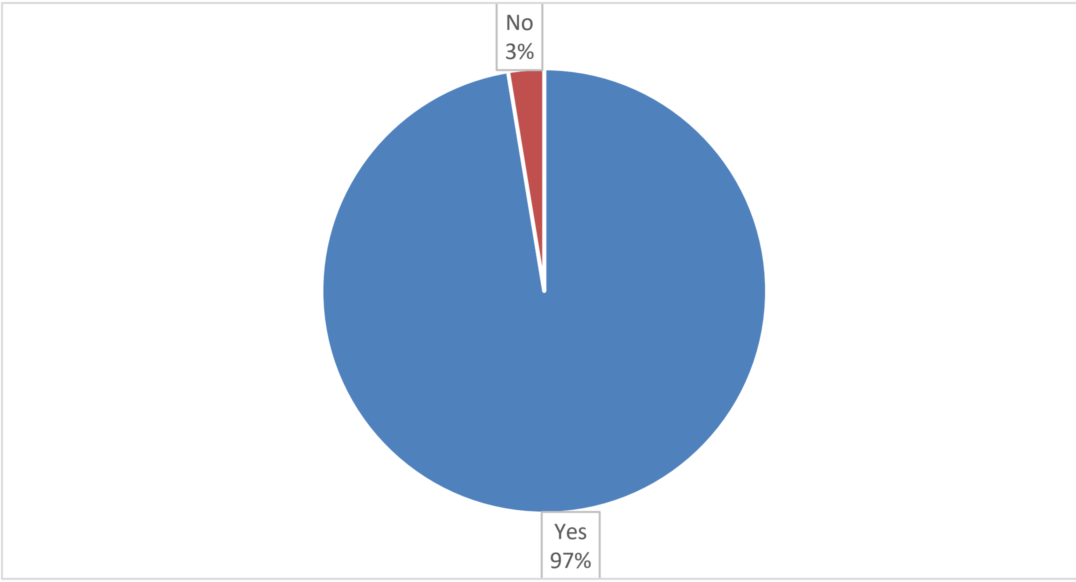
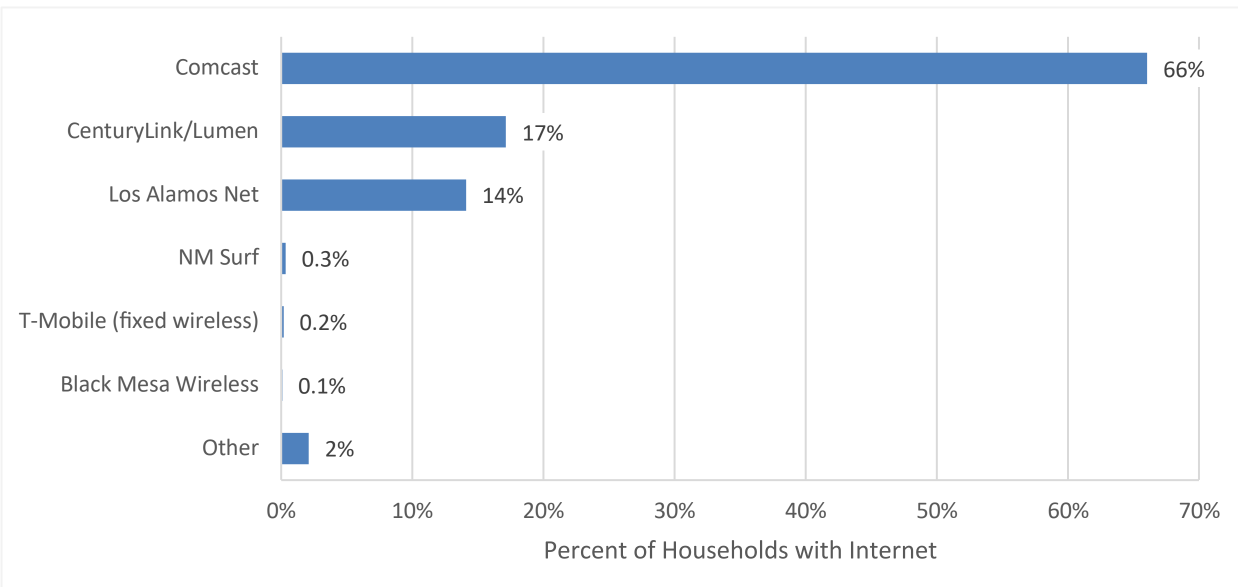
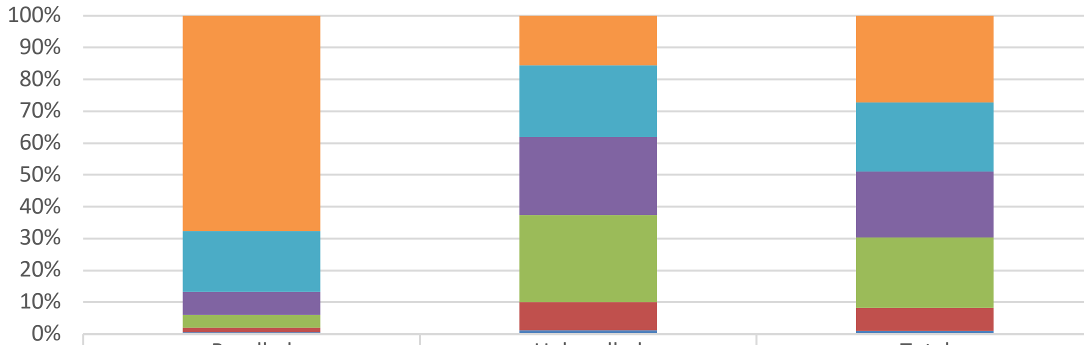


Figure 20: Primary internet service providers used



The data show that many respondents are paying relatively high prices for their internet service. Almost a third of respondents (27 percent) reported that they pay $100 or more per month for internet service. 22 percent pay between $80 and $99, and 21 percent pay between $60 and $79. Figure 21 shows the distribution of price paid for internet service bundled with other services as well as unbundled.

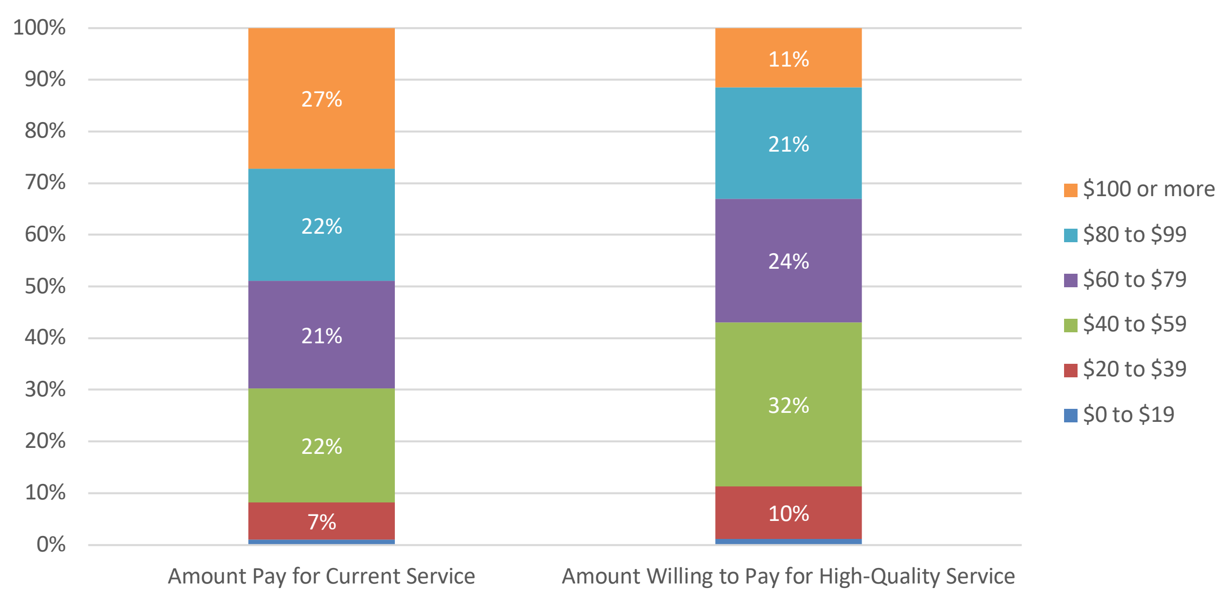
Figure 21: Monthly cost for internet service



	Bundled	Unbundled	Total
$100 or more	68%	16%	27%
$80 to $99	19%	22%	22%
$60 to $79	7%	25%	21%
$40 to $59	4%	27%	22%
$20 to $39	1%	9%	7%
$0 to $19	1%	1%	1%

When asked how much they would be willing to pay for high-quality internet service with little to no lag, 11 percent said they are willing to pay $100 or more per month, 21 percent of respondents said they would be willing to pay between $80 and $99, and 24 percent said they would be willing to pay between $60 and $79. Figure 22 shows the price that Los Alamos County residents are willing to pay for high-quality service compared to the price they are paying.

Figure 22: Price that residents are willing to pay for high-quality internet service



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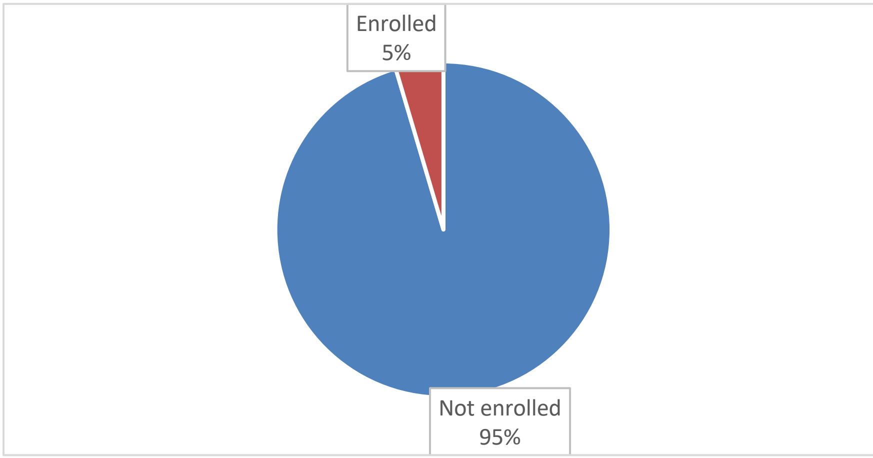
Very few respondents (5 percent) are enrolled in a subsidy program. The respondents who are enrolled are part of the Affordable Connectivity Program (ACP). Figure 23 shows subsidy program enrollment.

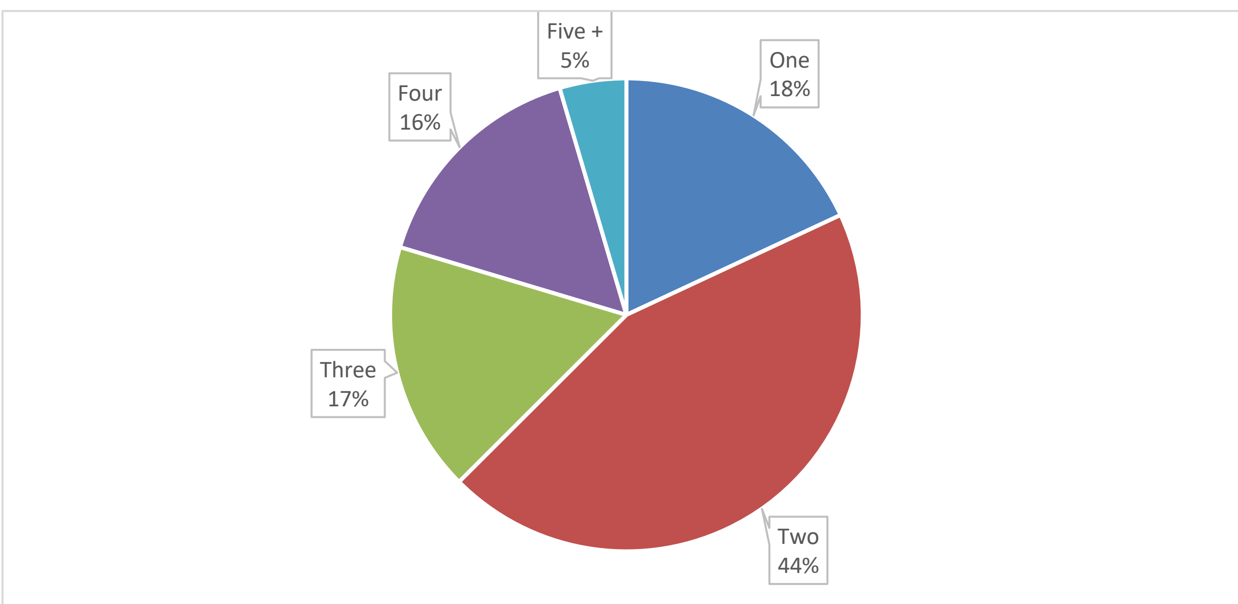
Figure 23: Percentage enrolled in a discount or subsidy program



5.3.2 Number of people using the internet and devices

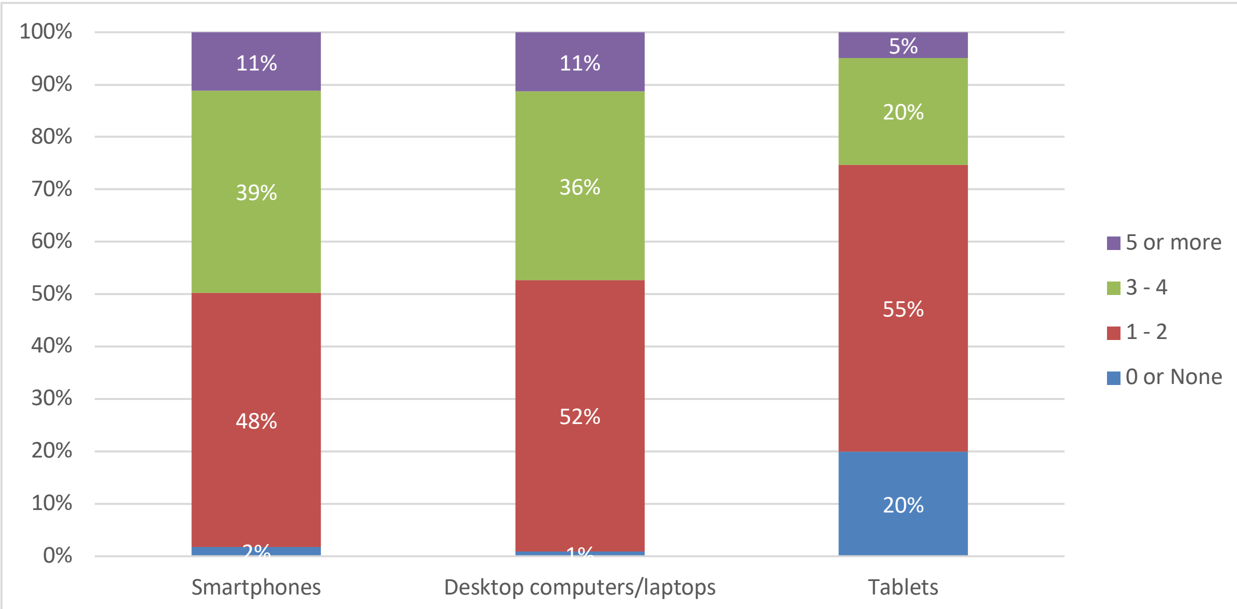
The majority of respondents (82 percent) claimed that two or more people in their household need to be online at the same time. Figure 24 demonstrates the number of simultaneous online users.

Figure 24: Number of users who need to be online at the same time



Over half reported using one or two devices in the household. 52 percent use one or two desktop computers, 55 percent use one or two tablets, and 48 percent use one or two smartphones. Figure 25 shows the type and quantity of devices used.

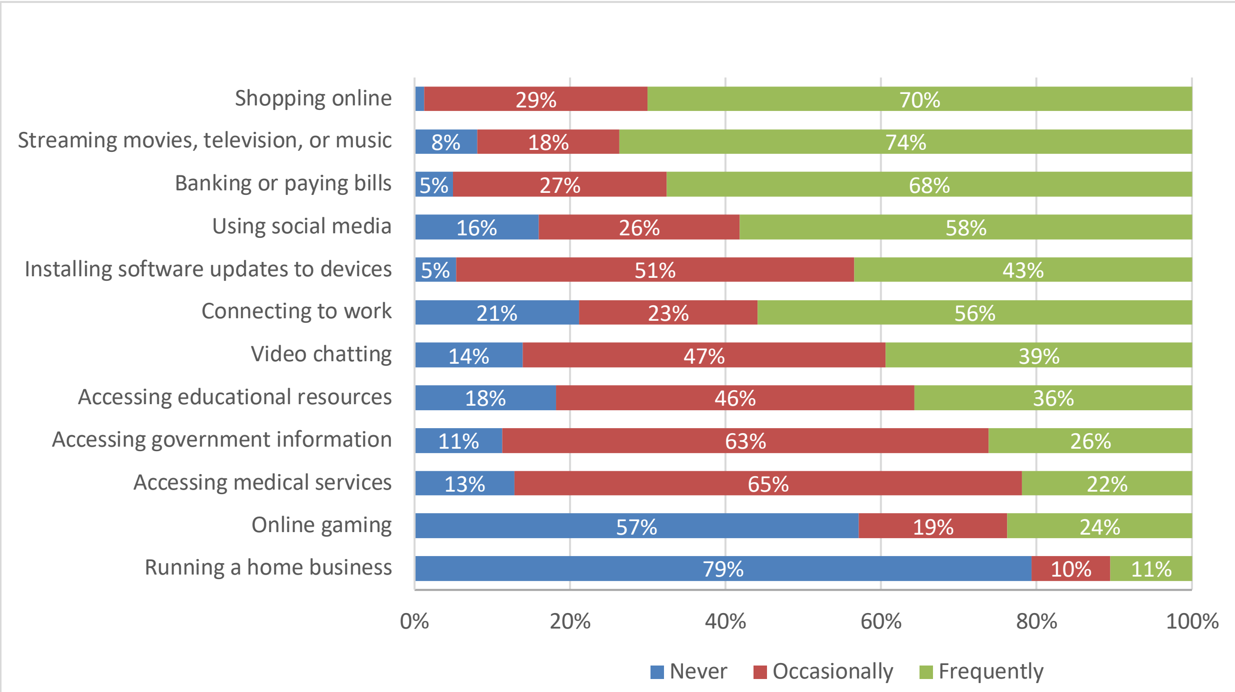
Figure 25: Number of devices used in the household



5.3.3 Purposes for internet usage and computer skills

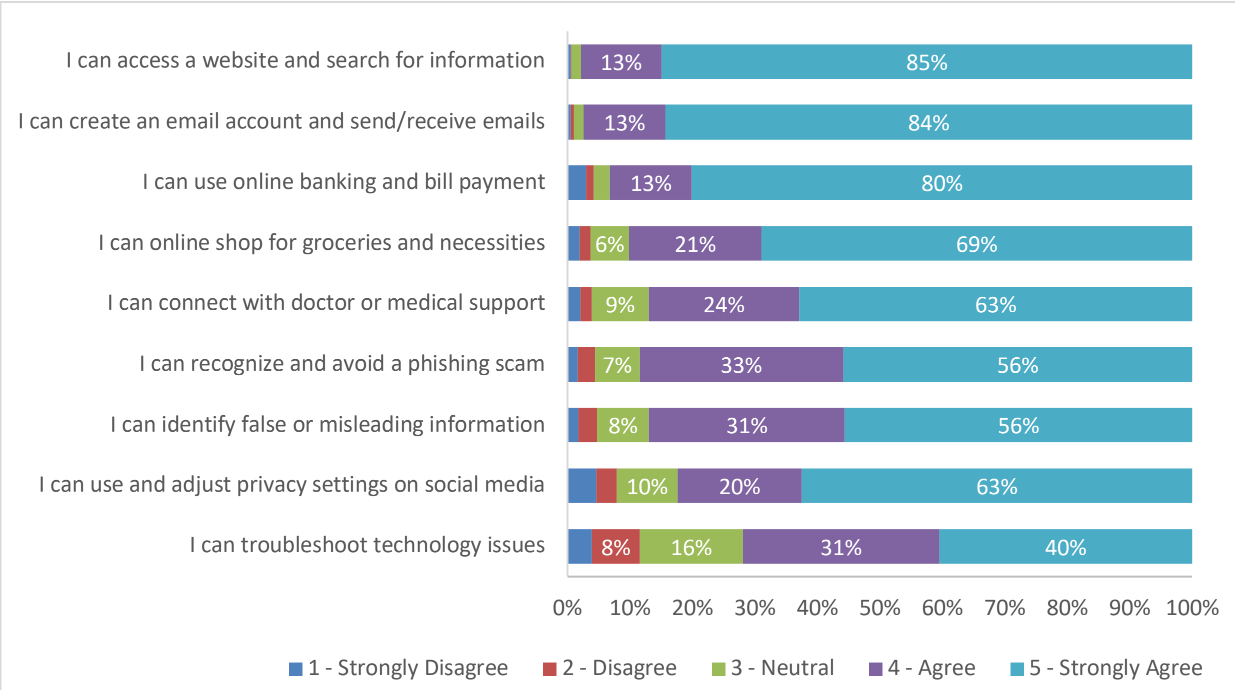
When asked about frequency of internet usage for different purposes, streaming movies, television or music (74 percent), shopping online (70 percent), and banking or paying bills (68 percent) were most often cited as frequently used. Only 11 percent of respondents use the internet to run a home business. Figure 26 shows the frequency of different online activities.

Figure 26: Purposes for using home internet connection



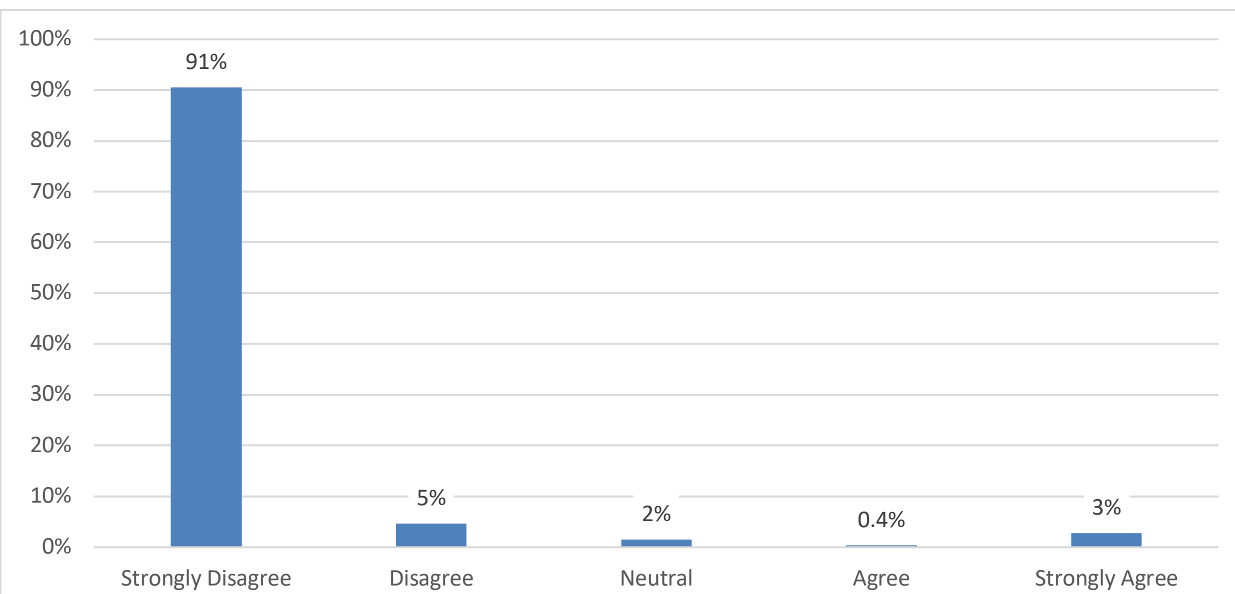
Computer and internet skills were generally strong among respondents. A majority strongly agreed they possessed the following skills: 85 percent are able to access websites and do an information search, 84 percent can create and email account and send/receive emails, and 80 percent are able to use online banking and bill payment. Figure 27 shows respondents' agreement with their ability to accomplish various online tasks.

Figure 27: Agreement with possession of computer and internet skills



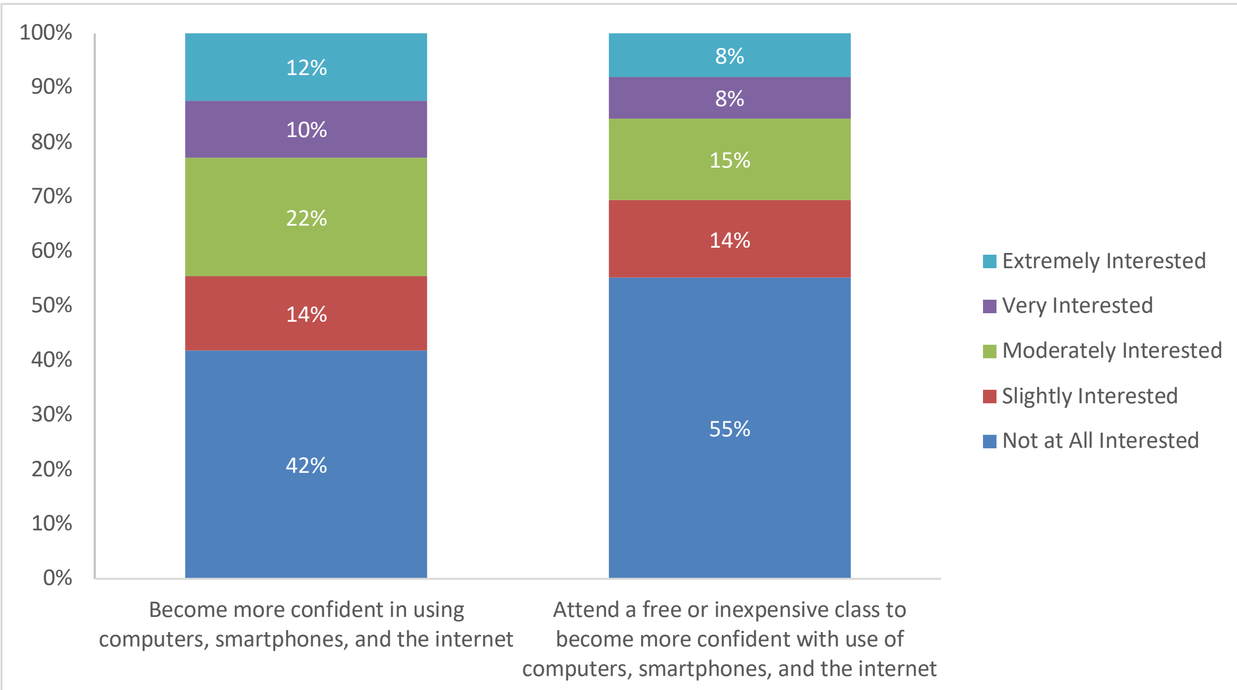
Language was not a barrier for the vast majority of respondents. Only 3 percent said they did not know English well enough to use the internet as shown in Figure 28.

Figure 28: Lack of English language skills preventing internet use



Respondents were generally confident in their computer skills and abilities. Under half of the respondents were interested in cultivating these skills. 55 percent were not at all interested attending a free or inexpensive class and 42 percent were not at all interested in becoming more confident using computers, smartphones and the internet. Figure 29 shows the level of interest in gaining skills.

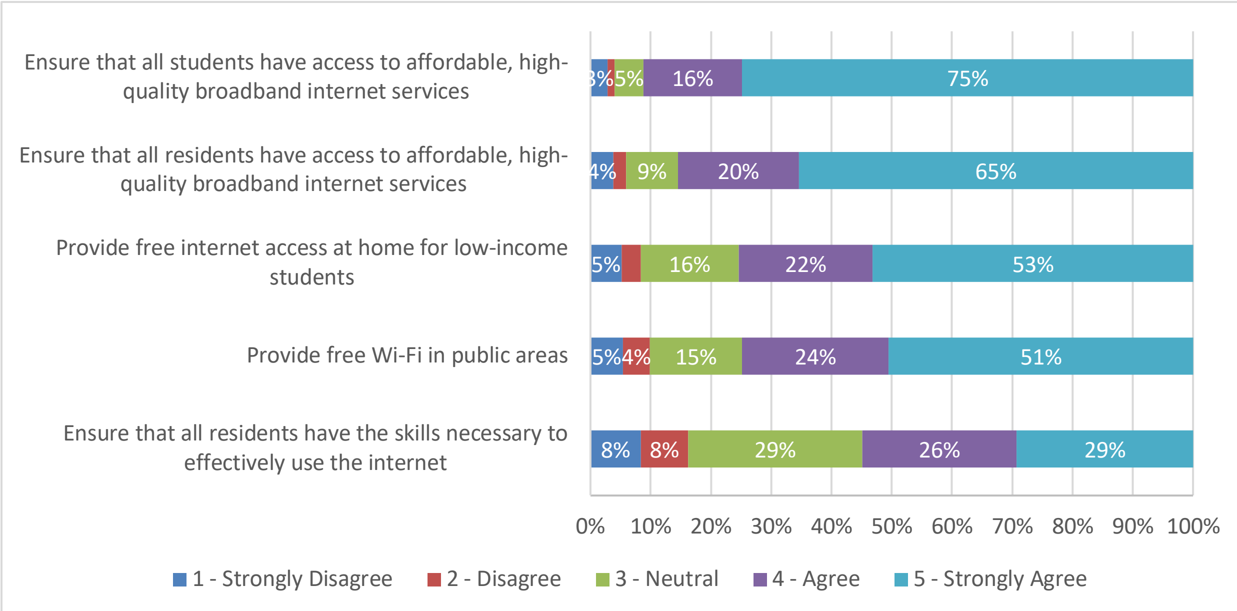
Figure 29: Interest in gaining computer skills



5.3.4 Priorities for the County

Regarding broadband services, respondents were strongly in favor of ensuring high quality, affordable broadband access to all residents and students. 75 percent strongly agreed that the County should ensure that all students have affordable and high-quality access, and 65 percent strongly agreed that all residents should have affordable and high-quality access to broadband. Figure 30 shows respondents' opinions regarding priorities for the County.

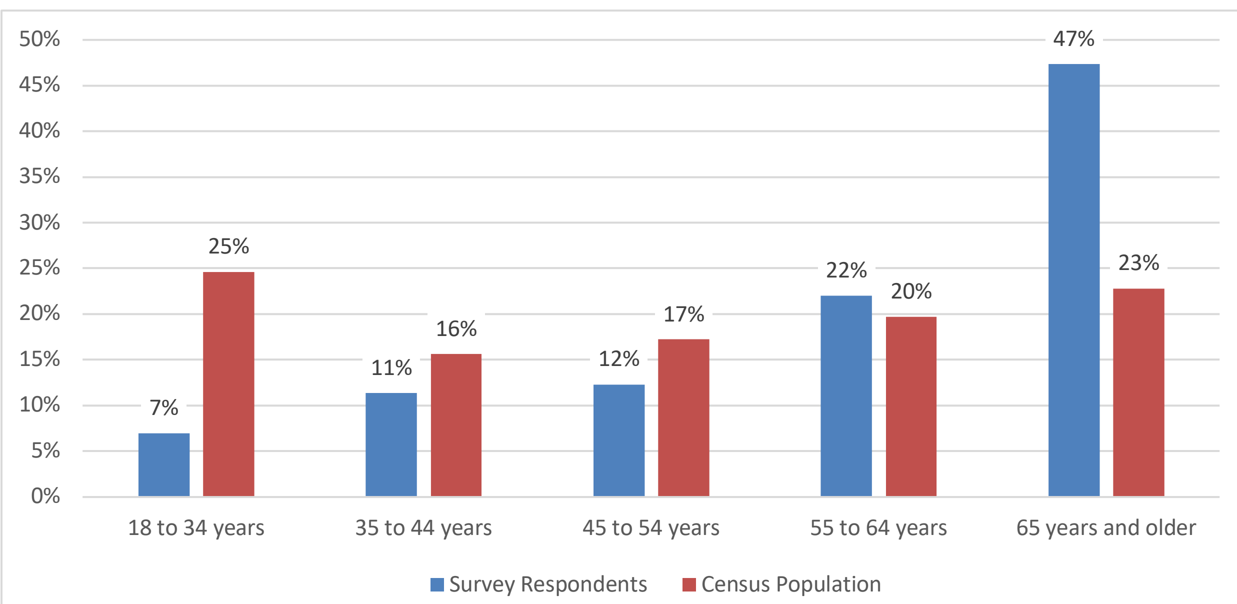
Figure 30: Support of the County's responsibility to deliver broadband



5.3.5 Demographics

Age of respondents skewed much older than the population as a whole. 47 percent of respondents are 65 or older, and 21 percent are between 55 and 64 years of age. Figure 31 shows the age distribution of respondents compared with census data.

Figure 31: Age of respondents compared to census



Most survey respondents were highly educated, with over half possessing a graduate, professional, or technical degree.

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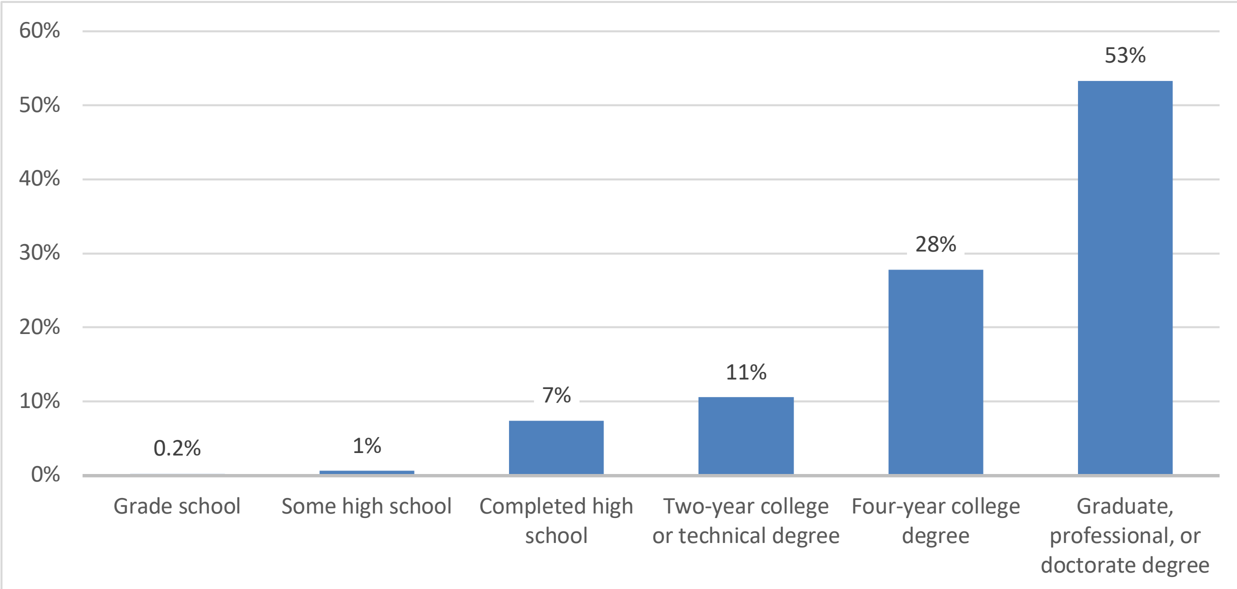
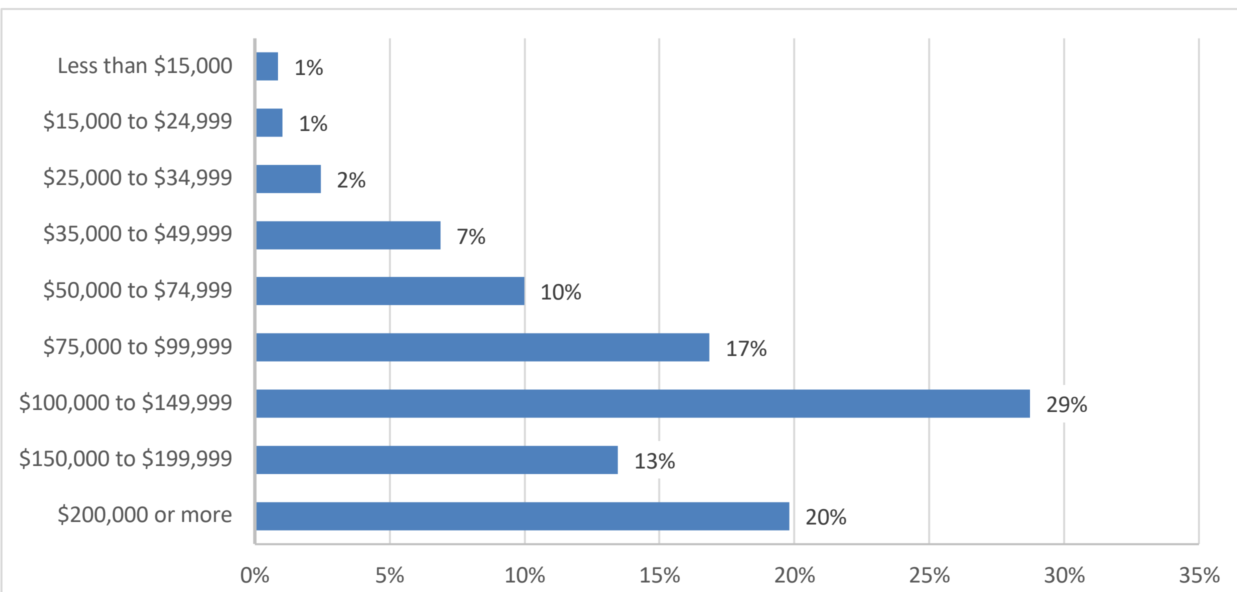
Figure 32: Highest level of education completed



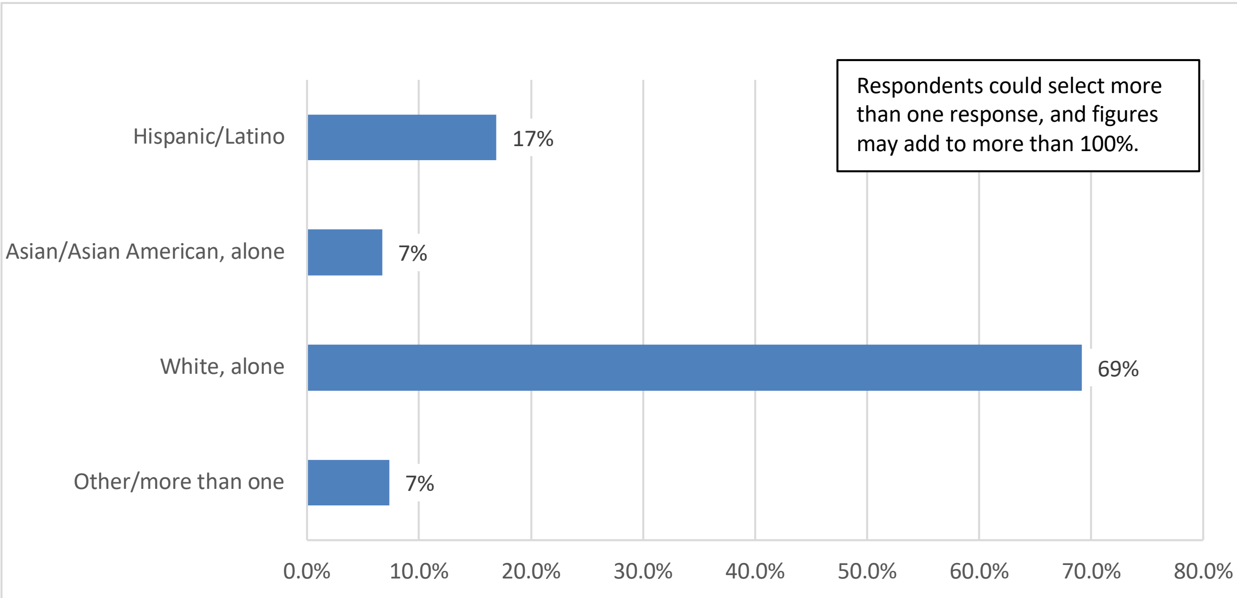
Reported income levels were relatively high. 29 percent have an annual household income of $100,000 to $149,999, and 20 percent have an income of $200,000 or more.

Figure 33: Annual household income



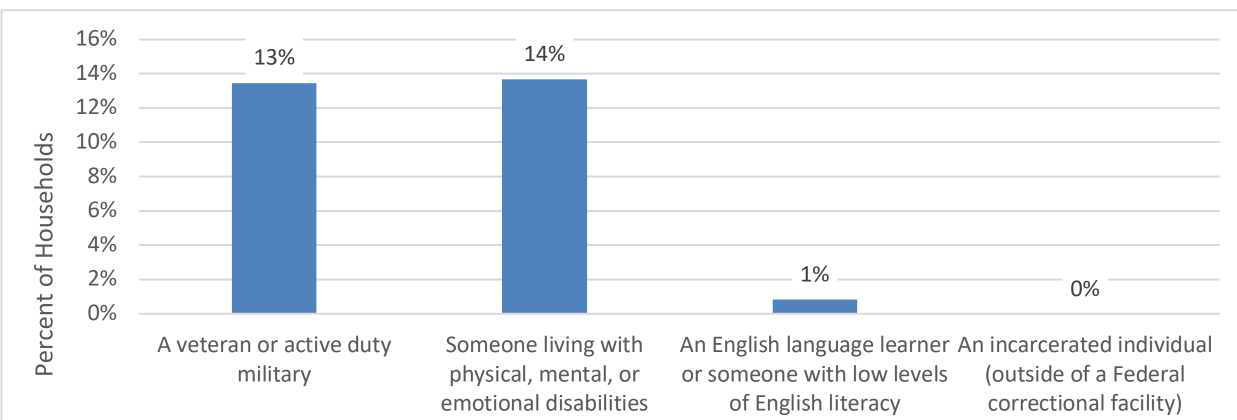
Respondents were overwhelmingly white (69 percent), with very little racial or ethnic diversity.

Figure 34: Race or ethnicity



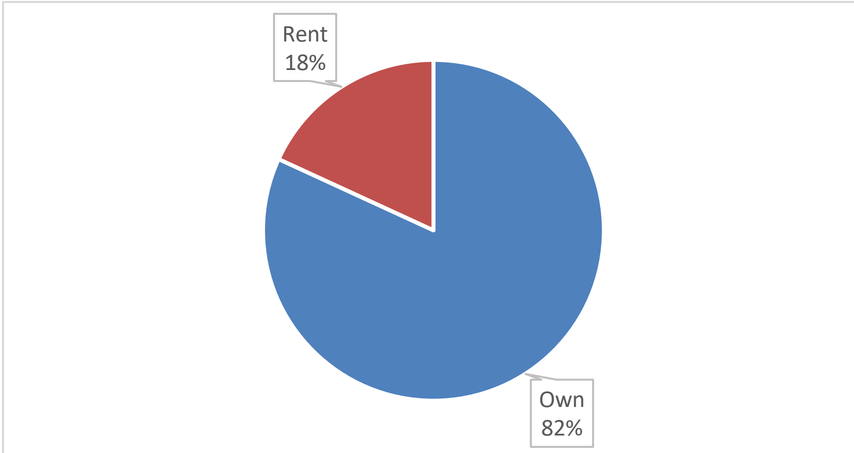
13 percent are veterans or active-duty military. 14 percent of households have a member living with physical, mental, or emotional disabilities. Almost no respondents were English language learners or incarcerated individuals.

Figure 35: Incidence of veterans, persons with disabilities, English language learners, and incarcerated individuals



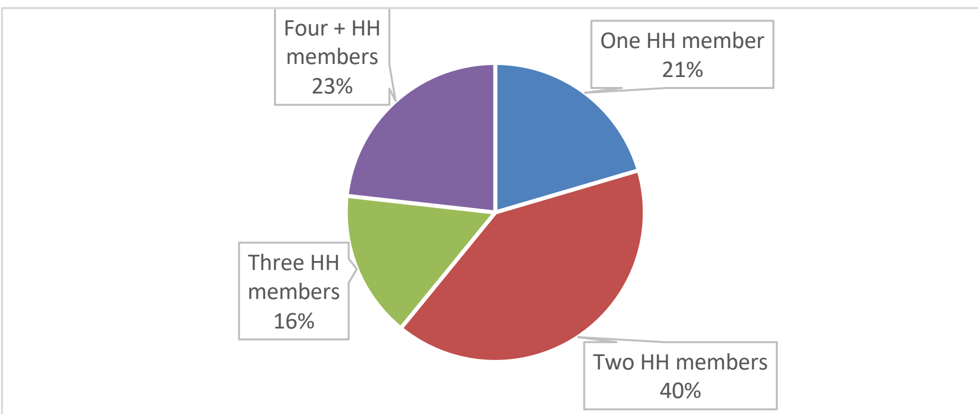
The vast majority of residents own their own homes.

Figure 36: Home ownership



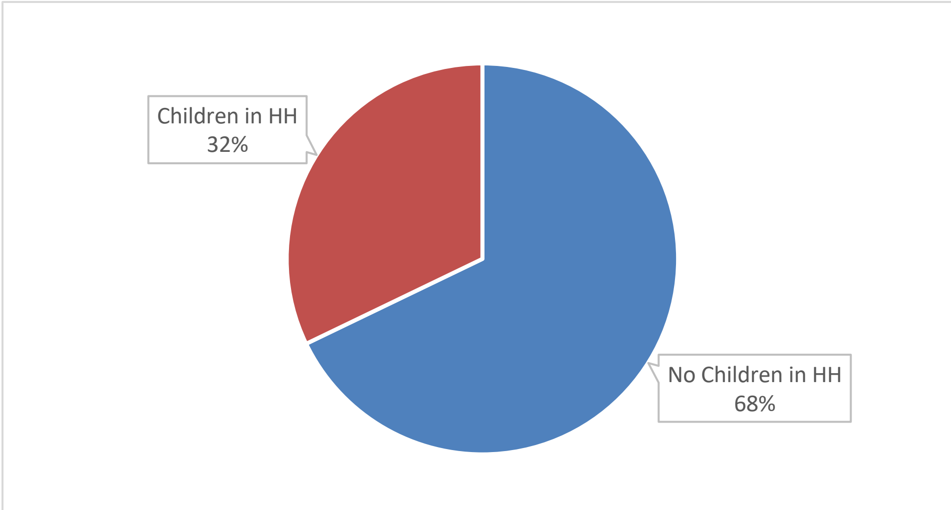
Household size was varied, with 40 percent of respondents in a household with two members.

Figure 37: Household size



Approximately two-thirds of respondents do not have children at home.

Figure 38: Children in household



5.4 Speed test survey results

The County also sponsored a speed test that incorporated a brief survey to capture service speeds and customer experience. The results (shown in Figure 39) largely confirmed anecdotal information from County stakeholders that existing incumbents are performing below expectations. The majority of subscribers received less than 100/20—rendering them effectively underserved—despite resident's desires for high-speed broadband. More concerning was the high number of test results that were below the minimum definition of broadband (at least 25/3), making subscribers effectively unserved. An analysis of these results showed that most were due to slow DSL speeds, but many were from cable coax subscribers. Figure 40 shows test results by provider.

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Figure 39: Map of speed test survey results

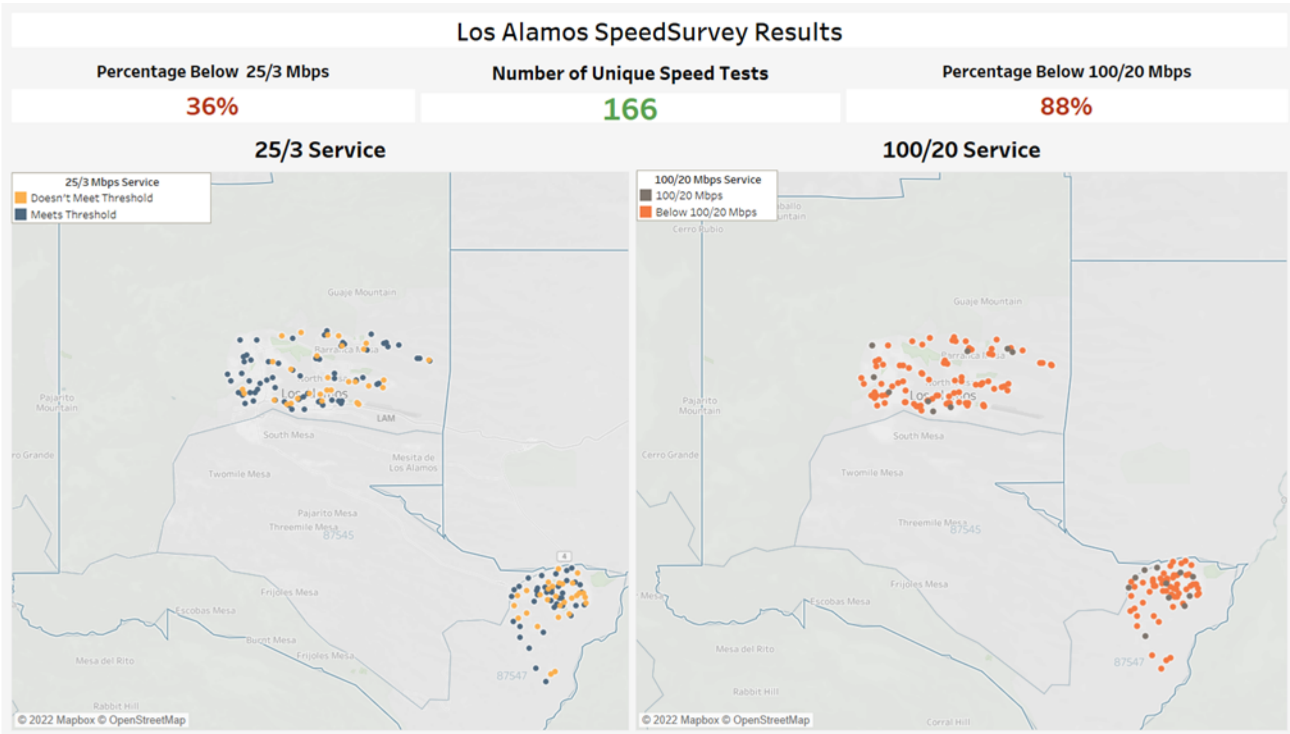

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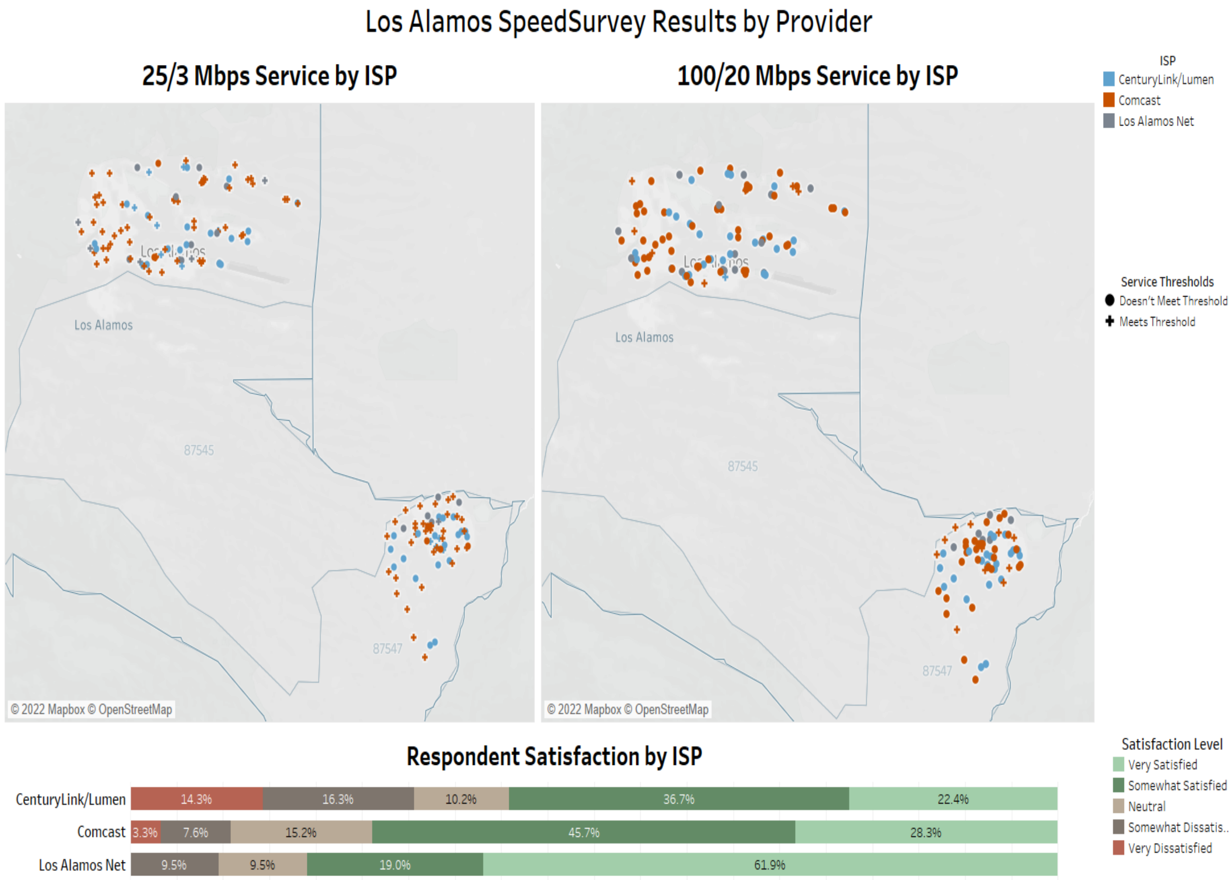
Figure 40: Map of speed test survey results by provider



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6 A candidate fiber-to-the-premises network design to serve the Los Alamos Townsite and White Rock would cost approximately $34 million

This report presents a conceptual, high-level network design and cost model that is able to support a variety of uses, including Los Alamos County's primary goal of providing fiber-to-the-premises (FTTP) service to the residents and businesses of Townsite and White Rock. The design aligns with best practices in the industry and reflects the County's goals for capacity, resilience, and scalability.

At the request of the County, CTC evaluated an FTTP network design created by Crestino Telecommunications for the County in 2013[26] when creating our design. However, FTTP technology has advanced significantly over the past decade, offering greater flexibility in the choice of network architecture and available services. While CTC's design shares some similarities with the Crestino design, such as using available infrastructure, this report presents an independent design and assumptions.

We present three primary designs:

- **Model A (Townsite)** is a standalone design intended to reach all addresses within the Los Alamos Townsite.
- **Model B (White Rock)** is a standalone design intended to reach all addresses within White Rock.
- **Models A and B combined** would build out both Townsite and White Rock and connect the two areas via existing County-owned middle-mile fiber located between the areas.

Table 15 summarizes the total implementation costs of each model. These costs are itemized in Section 6.3.

[26] Los Alamos County enlisted the services of Crestino Telecommunications to develop a plan to provide an open-access FTTP network capable of delivering speeds equal to or greater than 1 Gigabit per second to all residents and businesses in Los Alamos and White Rock. The report proposed building an active ethernet FTTP network at an initial cost of $47.2 million, with phased upgrades over three years at a total cost of $61 million.

Table 15: High-level cost estimate summary for the proposed designs

Description	Model A (Townsite)	Model B (White Rock)	Models A and B combined
Total fixed costs (with 20 percent contingency)[27]	$17,380,000	$9,120,000	$26,550,000
Total passings	7,198	2,816	10,014
Total fixed cost per passing	$2,400	$3,240	$2,650
Distribution network electronics, subscriber drops, and CPE (60 percent take-rate)	$5,523,000	$1,877,000	$7,400,000
Number of subscribers (60 percent take-rate)	4,318	1,690	6,008
Total implementation costs	$22,903,000	$10,997,000	$33,950,000
Cost per subscriber	$5,300	$6,500	$5,650

The cost of building an FTTP network will depend on what percentage of the network infrastructure is built on aerial poles as opposed to inside underground conduit. All three models assume that the County seeks to maximize the use of existing utility poles where possible and will utilize underground construction in areas where aerial construction is not feasible. The designs assume a mix of 46 percent underground and 54 percent aerial construction.

Existing County assets were leveraged where possible when developing the cost estimates. According to information provided by the County, Townsite and White Rock combined have a total of approximately 23 miles of existing conduit and 9 miles of fiber infrastructure that are available for use. Use of existing conduit would reduce the total cost of the combined network by $3.1 million. Leveraging the existing fiber between Townsite and White Rock would save approximately $1.4 million in additional construction costs by eliminating the need to build a new middle-mile connection. Lastly, hubsites were placed at County-owned facilities to offset the costs of leasing or purchasing property. These savings have been included in the cost estimates.

6.1 FTTP network architecture

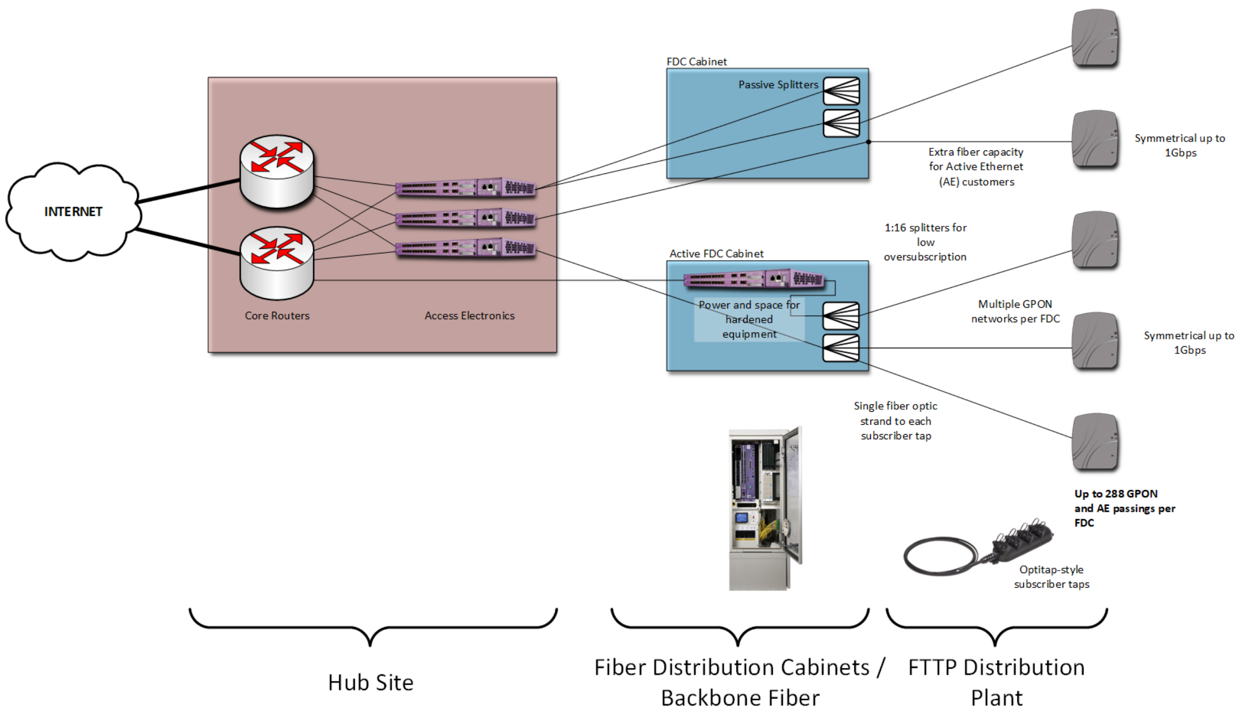
CTC developed a conceptual, high-level FTTP outside plant network design that is aligned with industry best practices and supports a variety of electronic architecture options.[28] Figure 41,

[27] Fixed costs are the costs associated with building the backbone and distribution network, and do not include subscriber drops or distribution network electronics directly related to subscribers. The cost to build this part of the network will not change based on take-rate.

[28] The network's outside plant is both the most expensive and the longest-lasting portion of the deployment. The architecture of the physical plant determines the network's scalability for future uses and how the plant will need to be operated and maintained; the architecture is also the main determinant of the total cost of the deployment.

below, shows a logical representation of the FTTP network architecture we recommend based on the conceptual outside plant design.

Figure 41: High-level fiber-to-the-premises architecture



This drawing illustrates the primary functional components in the FTTP network, their relative position to one another, and the flexibility of the architecture to support multiple subscriber models and classes of service.

The recommended architecture is a hierarchical data network that provides critical scalability and flexibility, both in terms of initial network deployment and its ability to accommodate the increased demands of future applications and technologies. The characteristics of this hierarchical FTTP data network are:

- **Capacity** – ability to consistently provide efficient transport for subscriber data at advertised speeds, even at peak times
- **Availability** – high levels of redundancy, reliability, and resiliency; the ability to quickly detect faults and reroute traffic
- **Efficiency** – no traffic bottlenecks; efficient use of resources

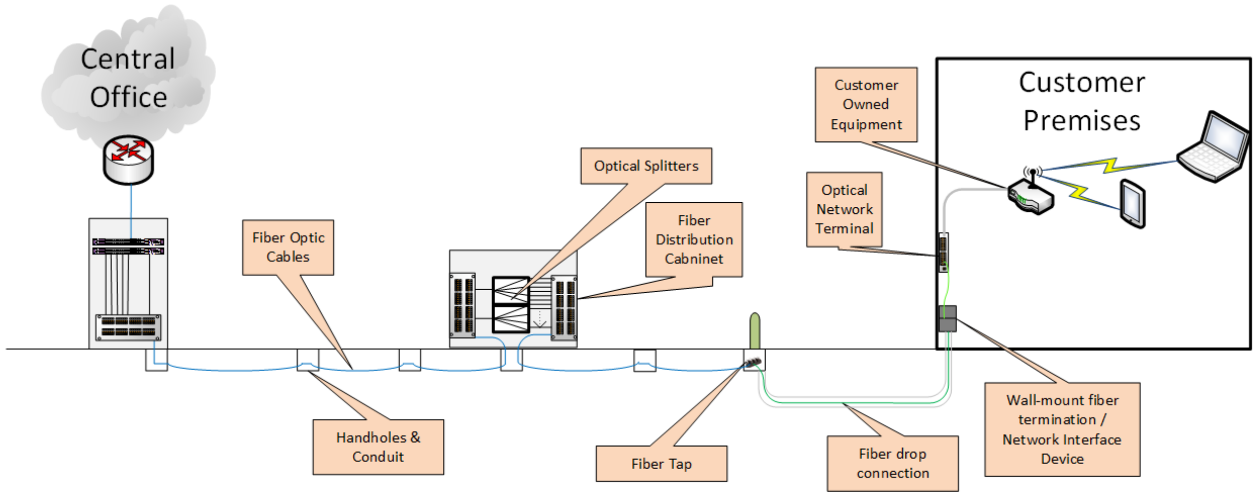
- **Scalability** – ability to grow in terms of physical service area and increased data capacity, and to integrate newer technologies without new construction
- **Flexibility** – ability to provide different levels and classes of service to different customer environments; can support an open access network or a single-provider network; can provide separation between service providers on the physical layer (separate fibers) or logical layer (separate Virtual Local Area Network (VLAN) or Virtual Private Network (VPN) providing networks within the network)
- **Security** – controlled physical access to all equipment and facilities, plus network access control to devices

This architecture offers scalability to meet long-term needs. It is consistent with best practices for either a standard or an open-access network model to provide customers with the option of multiple network service providers. This design would support the current industry standard Gigabit Passive Optical Network (GPON) technology, as well as 10 Gbps XGS-PON and NG-PON2 standards. It could also provide the option of direct Active Ethernet (AE) services on a limited basis, such as for business customers, using spare fiber capacity built into the designs.

For purposes of the distribution electronics and the customer premise equipment, the design is based on a GPON architecture, which is the most commonly provisioned fiber-to-the-premises service—used, for example, by AT&T Fiber, Verizon (in its FiOS systems), and Google Fiber. GPON supports high-speed broadband data and is easily leveraged by triple-play carriers for voice, video, and data services.

GPON uses passive optical splitting, which is performed inside fiber distribution cabinets (FDC), to connect fiber from the Optical Line Terminals (OLT) to the customer premises where it connects to an Optical Node Terminal (ONT) on the outside or inside of the premises. With GPON service (Figure 42), the FDCs house multiple optical splitters, each of which splits the fiber link to the OLT between 16 to 32 customers. The GPON OLT uses single-fiber (bi-directional) modules called Small Form Factor Pluggable (SFP), which consist of a laser transmitter and a receiver to support multiple (less than 32) subscribers, so each customer receives a fiber connection all the way to the premises.

Figure 42: GPON fiber network with a buried service drop



The design assumes placement of manufacturer-terminated fiber tap enclosures within the public right-of-way or easements, providing watertight fiber connectors for customer service drop cables, and eliminating the need for service installers to perform splices in the field. This is an industry-standard approach to reduce both customer activation times and the potential for damage to distribution cables and splices.

The chief advantage of this type of architecture lies in the simple and passive design which makes installation straightforward, and is very cost effective to operate, with few active pieces that can break. Even though the GPON (Gigabit Passive Optical Network) platform is limited to 1.2 Gbps upstream and 2.4 Gbps downstream for the subscribers connected to a single PON (meaning the bandwidth available to the individual subscriber needs to be divided with others on the PON), operators have found that the variations in actual subscriber usage generally means that all subscribers can obtain 1 Gbps symmetrical on demand (without provisioned rate-limiting), even if the capacity is aggregated at the PON.

The platform has also proven to be versatile: many GPON manufacturers have developed technology to support up to 10 Gbps and faster speeds as user demand increases, and these are already implemented by many providers delivering business services.[29] In fact, part of the attraction of GPON technology is that much of the infrastructure can be upgraded in a relatively easy and cost-effective manner. Some OLTs already support the next generation PON technologies (such as XGS-PON and NGPON2)[30], so much of the GPON investment can be reused,

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

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

and upgrades can be done incrementally as needed. XGS-PON is a symmetric, higher bandwidth version of GPON. Being a PON solution, it features the same capabilities as GPON and can co-exist on the same fiber with GPON. XGS-PON benefits from the efficiencies of a point-to-multipoint architecture but enables operators to assure Gigabit and multi-Gigabit speeds to end subscribers. With the prevailing availability of multiple ONU chipset providers and the reduced transceiver costs, XGS-PON is becoming the technology of choice for many operators.

6.2 Assumptions and criteria

The FTTP network design was developed with the following criteria and required characteristics of the hierarchical FTTP network:

- Underground conduit and fiber will be installed in the public right-of-way or in an easement on the side of the road.
- The aerial fiber design will make use of existing poles where possible.
- The underground design will make use of existing conduit and backbone fiber where available.
- Primary and secondary distribution cables will be 288-count cables; extended lateral fiber sizes will range from 48- to 144-count cable; and short lateral and drop fiber will contain 12 strands.
- The network will target up to 288 passings per secondary distribution point, each served from an FDC containing optical splitters.
- The distribution plant will terminate at multi-port subscriber tap terminals (i.e., “taps”) in underground handholes, each serving no more than 12 homes.
- Access conduit will be placed in drop access handholes placed at the edge of the parcel for each serviceable passing (one handhole per one or two passings).
- The underground vault spacing along distribution routes will be no more than 750 feet.
- Where possible, the distribution plant network routes will avoid crossing major roadways, railways, and waterways.
- In the aerial design we assume that the builder is able to obtain an attachment agreement from the pole owner where non-County-owned poles are used.

Figure 43 below shows the conceptual architecture for the physical plant in the fiber-to-the-premises network. A hub will feed primary distribution cable through distribution vaults located throughout the County. Some distribution vaults will be designated as equipment vaults, which contain splitters to feed secondary distribution conduit to tap access handholes located near residents. Each tap access handhole will then connect to drop access handholes located on the edge of the parcel but still within the County's right-of-way. By installing infrastructure all the way to the edge of each premises parcel, costs are reduced the costs for future installation to a subscriber.

Figure 43: Conceptual design for the fiber-to-the-premises network

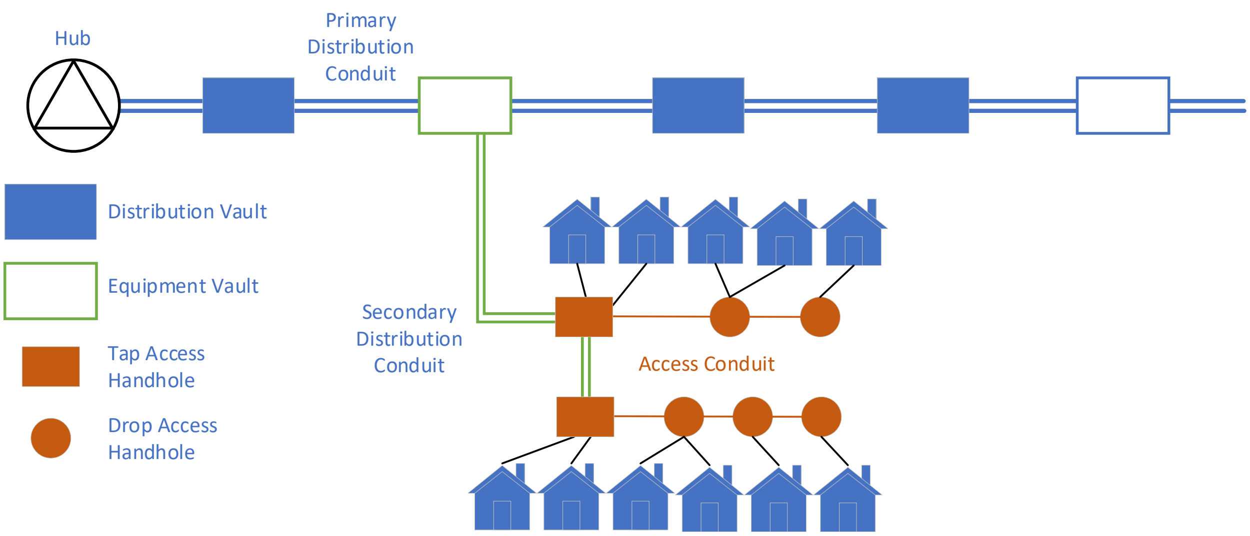
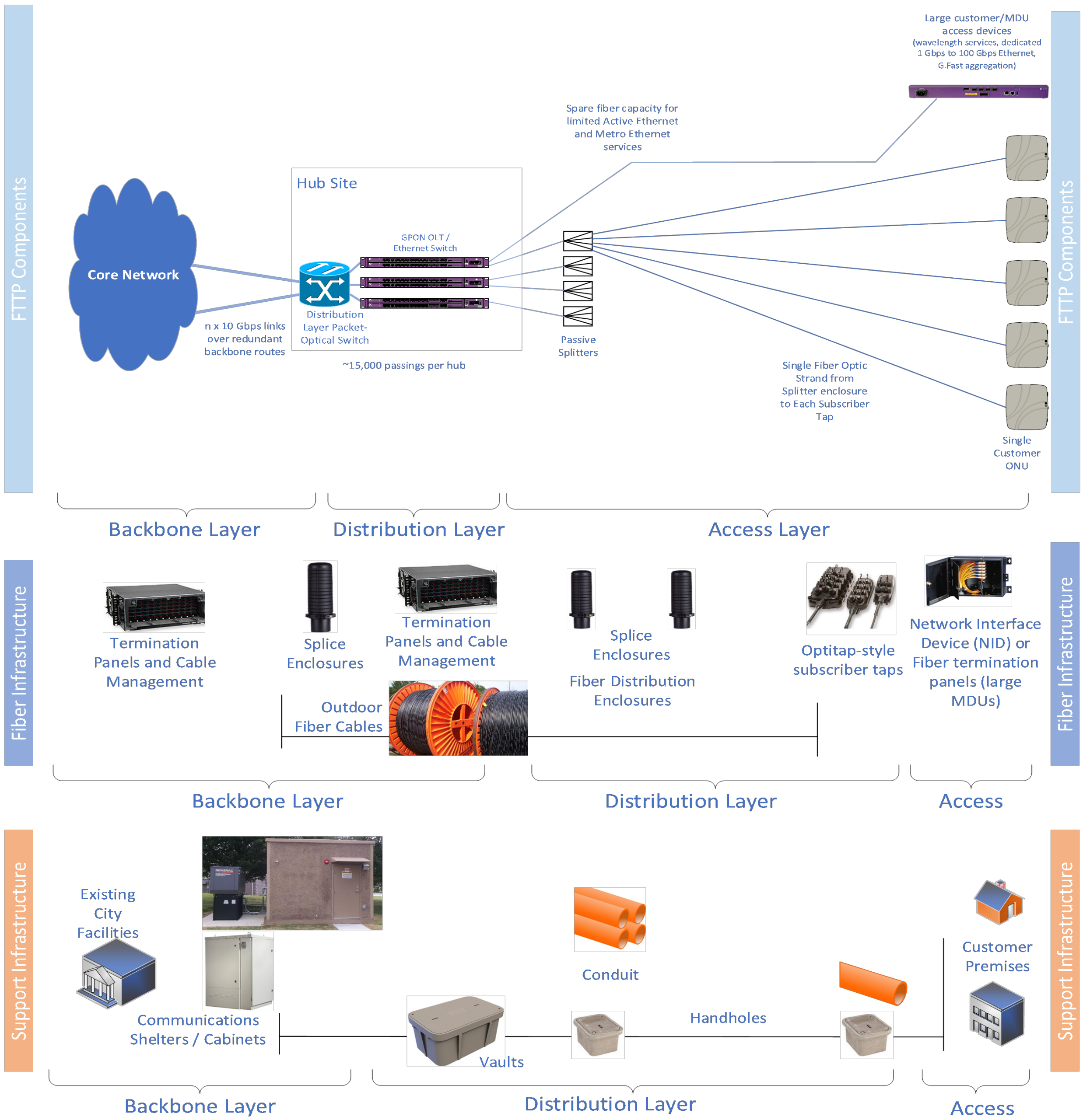


Figure 44 shows a logical representation of the FTTP network architecture we recommend based on the conceptual outside plant design. It also illustrates the primary functional components in the FTTP network, their relative position to one another, and the flexibility of the architecture to support multiple subscriber models and classes of service.

Figure 44: High-level fiber-to-the-premises architecture and components



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6.3 Estimated deployment costs

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

- **Project management** encompasses overall project and contract management, including oversight of the construction and engineering contractor(s), equipment suppliers, and right-of-way agreements. We assume that the combined Townsite and White Rock design would require one person for three years. To generate independent estimates, we assigned 2/3 of this cost to Townsite and 1/3 to White Rock.

- **Engineering and as-builts** includes system-level architecture planning, preliminary designs, and field walkouts to determine candidate fiber routing; development of detailed engineering prints and preparation of permit applications; and post-construction "as-built" revisions to engineering design materials.

- **Conduit and vault infrastructure** consists of all labor and materials related to underground communications conduit construction, including conduit placement, vault/handhole installation, and surface restoration; and includes all work area protection and traffic control measures inherent to roadway construction activities.

- **Utility pole make-ready** consists of the labor needed for preparing poles for the addition of new aerial cabling. This includes moving existing cables to make room for new cables or replacing poles if the existing pole is at maximum capacity.

- **Fiber optic cables and components** consists of the material and labor costs specific to the installation of fiber optic cables, taps, splice enclosures, and other related components, irrespective of the cable pathway (underground conduit or aerial placement).

- **Fiber splicing, testing, and documentation** includes all labor related to splicing of outdoor fiber optic cables.

- **Hub facilities and systems** consists of the material and labor costs of placing cabinets to house hubsite electronics and terminating backbone fiber cables within the hubs.

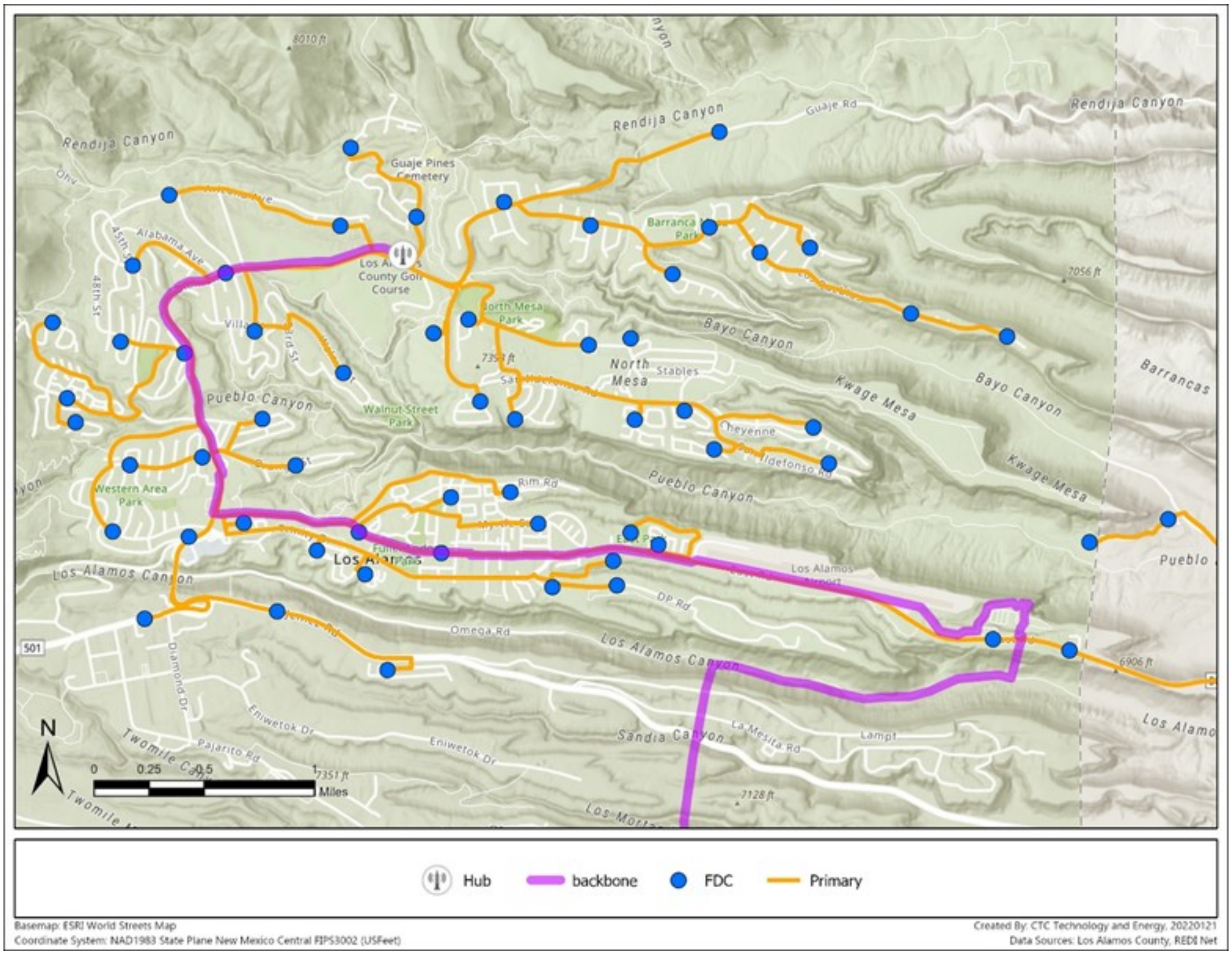
- **Post-Covid-19 market demand contingency** accounts for price increases on material due to supply chain interruptions during the Covid-19 pandemic. This contingency is not applied to the project management and engineering and as-builts categories because they do not incorporate construction material.

We also provide the estimated cost for FTTP distribution electronics, subscriber drops, and customer premises equipment (CPE). The cost for drops represents the materials and labor for installing aerial or underground infrastructure across a subscriber's property; CPE, such as a modem, is a separate expense.

6.3.1 Model A (Townsite)

Model A, shown in Figure 45, is designed to reach all addresses within the Los Alamos Townsite.

Figure 45: Model A (Townsite) high-level design overview



The backbone and distribution plant for Model A is estimated to cost $17.4 million, or approximately $2,400 per passing, including a 20 percent contingency cost on construction material. These costs are itemized below in Table 16. Note that the costs have been rounded.

Table 16: Estimated fixed costs for Model A (Townsite)

Cost element	Cost
Project management	$630,000
Engineering and as-builts	$1,150,000
Conduit and vault infrastructure	$8,300,000
Materials	$1,250,000
Labor	$7,050,000
Aerial strand	$450,000
Materials	$100,000
Labor	$350,000
Utility pole make-ready	$550,000
Fiber optic cables and components	$1,900,000
Materials	$1,300,000
Labor	$600,000
Fiber splicing, testing, and documentation	$450,000
Hub facilities and systems	$450,000
Core network electronics	$1,100,000
Distribution plant total cost	**$14,980,000**
Post-Covid-19 market demand contingency on construction material (20%)	$2,400,000
Distribution plant total cost with contingency	**$17,380,000**
Number of passings	7,198
Cost per passing	**$2,415**

Table 17 presents the estimated costs for the FTTP distribution network electronics, subscriber drop costs, and CPE. As not all addresses will choose to sign up for service, we have estimated a take-rate of 60 percent.

Table 17: Estimated distribution network electronics, subscriber drop, and CPE costs for Model A (Townsite)

Cost element	Cost
Number of subscribers	4,318
FTTP distribution network electronics	$850,000
Subscriber drop costs (including MDU wiring)	$2,673,000
Customer premises equipment (ONT/router)	$2,000,000
Total cost	**$5,523,000**
Cost per subscriber	**$1,279**

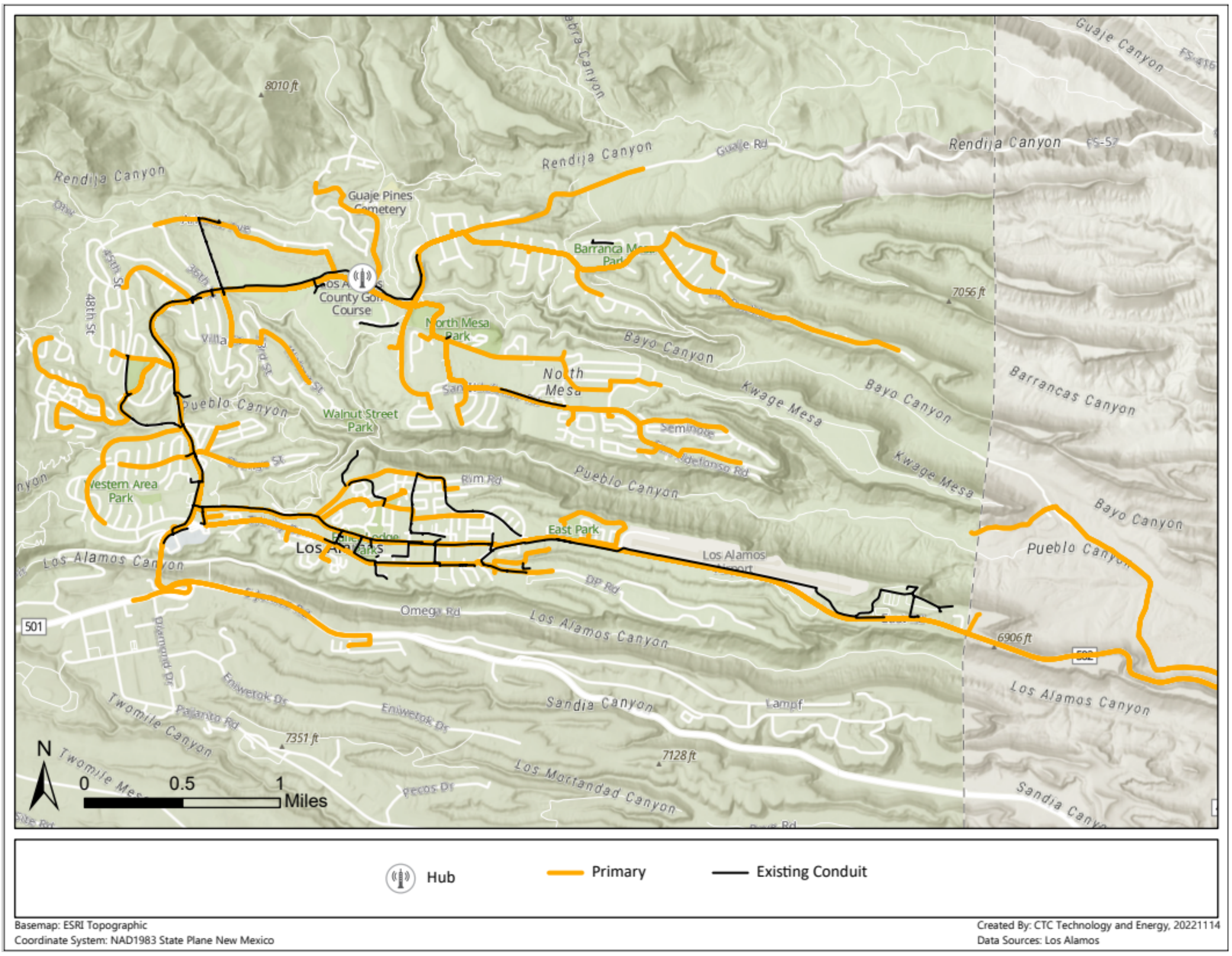
Table 18 presents the estimated total implementation costs for Model A, assuming a 60 percent take-rate. The total implementation cost is estimated to be $20.5 million. The total implementation cost with a 20 percent contingency on construction material is estimated to be $22.9 million, or $5,303 per subscriber.

Table 18: Estimated total implementation costs for Model A (Townsite)

Cost element	Cost
Total implementation costs	$20,503,000
Total implementation costs (with contingency)	$22,903,000
Total implementation cost per subscriber at 60% take rate	$5,303

The primary hubsite is placed at a County-owned facility, Fire Station #4, along the existing middle-mile connection between White Rock and the Townsite in order to take advantage of County-owned fibers along that route (see Figure 45). The County also owns an estimated 22.2 miles of existing conduit in the Townsite area that overlaps with the FTTP design, as shown in Figure 46. Use of this conduit would save $2.9 million. These savings have been included in the cost estimate.

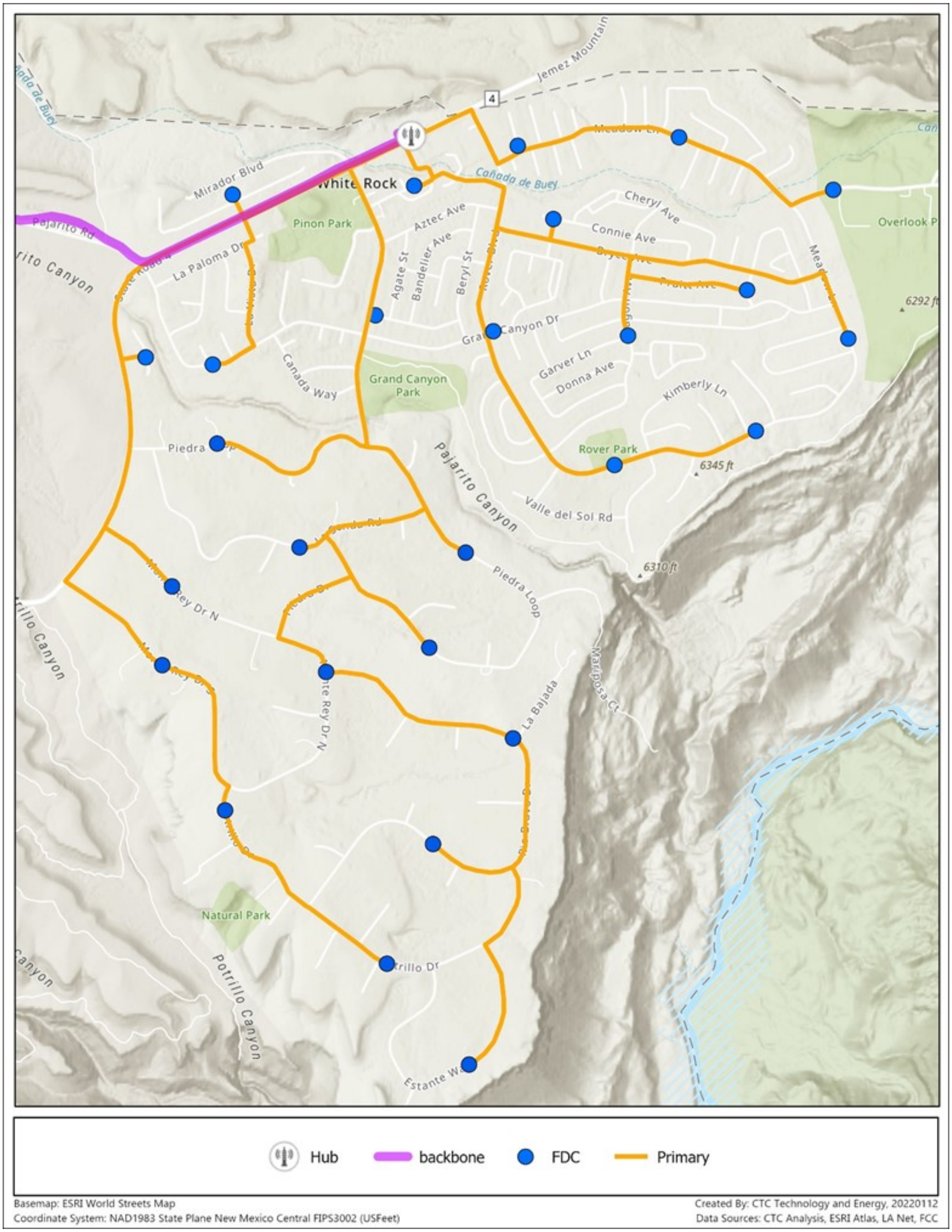
Figure 46: Areas of existing conduit overlap with Model A



6.3.2 Model B (White Rock)

Model B, shown in Figure 47, is designed to reach all addresses within White Rock.

Figure 47: Model B (White Rock) high-level design overview



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The backbone and distribution plant for Model B is estimated to cost $9.1 million, or $3,240 per passing, including a 20 percent contingency cost on construction material. These costs are itemized below in Table 19. Note that the costs have been rounded.

Table 19: Estimated fixed costs for Model B (White Rock)

Cost element	Cost
Project management	$270,000
Engineering and as-builts	$500,000
Conduit and vault infrastructure	$4,650,000
Materials	$650,000
Labor	$4,000,000
Aerial strand	$200,000
Materials	$50,000
Labor	$150,000
Utility pole make-ready	$250,000
Fiber optic cables and components	$850,000
Materials	$600,000
Labor	$250,000
Fiber splicing, testing, and documentation	$250,000
Hub facilities and systems	$450,000
Core network electronics	$400,000
Distribution plant total cost	**$7,820,000**
Post-Covid-19 market demand contingency on construction material (20%)	$1,300,000
Distribution plant total cost with contingency	**$9,120,000**
Number of passings	2,816
Cost per passing	**$3,240**

Table 20 presents the estimated costs for FTTP distribution electronics, subscriber drops, and CPE. As not all addresses will choose to sign up for service, we have estimated a take-rate of 60 percent.

Table 20: Estimated distribution network electronics, subscriber drop, and CPE costs for Model B (White Rock)

Cost element	Cost
Number of subscribers	1,690
FTTP distribution network electronics	$350,000
Subscriber drop costs (including MDU wiring)	$727,000
Customer premises equipment (ONT/router)	$800,000
Total cost	**$1,877,000**
Cost per subscriber	**$1,111**

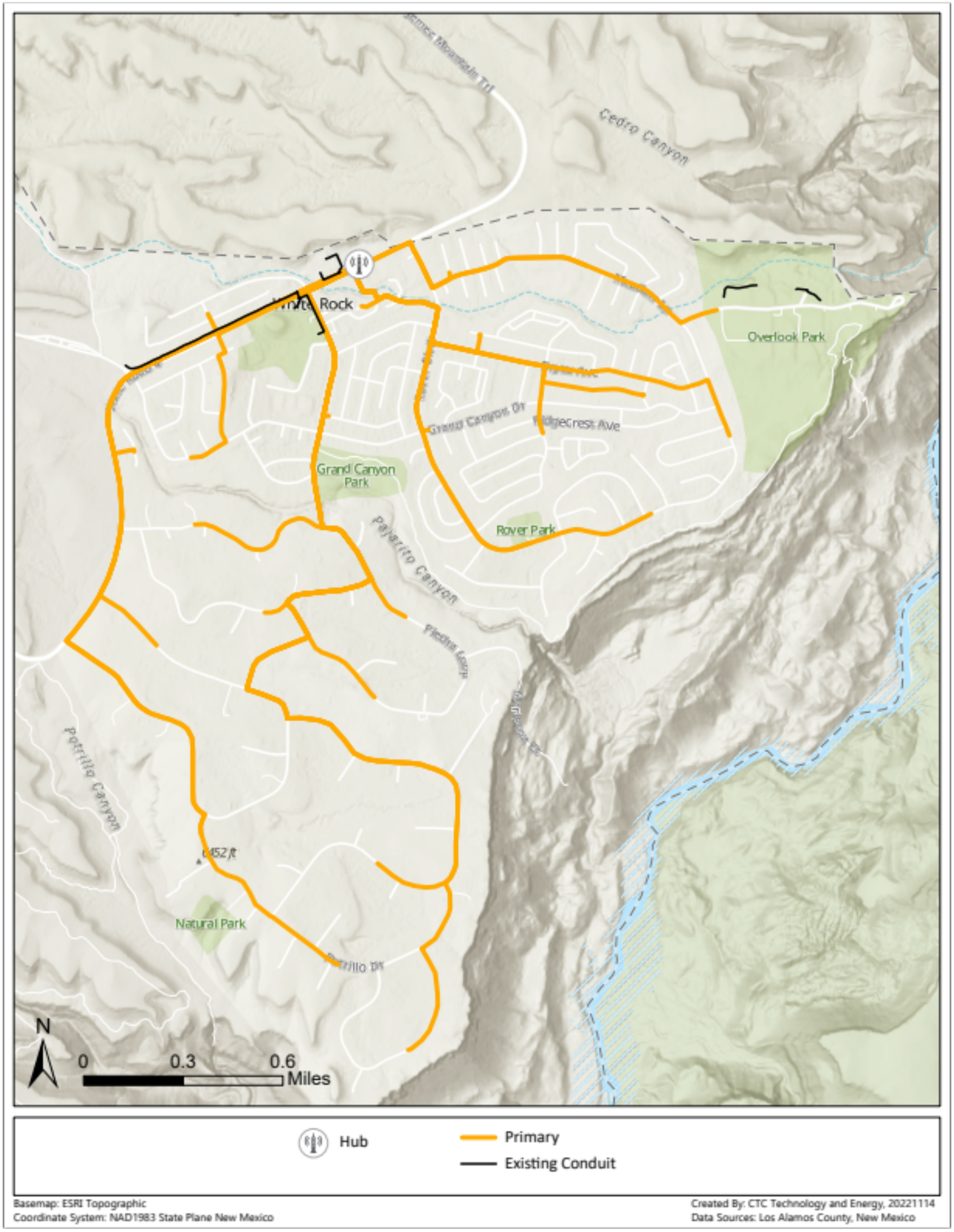
Table 21 presents the estimated total implementation costs for Model B, assuming a 60 percent take-rate. The total implementation cost is estimated to be $9.7 million. The total implementation cost with a 20 percent contingency on construction material is estimated to be $11 million, or $6,509 per subscriber.

Table 21: Estimated total implementation costs for Model B (White Rock)

Cost element	Cost
Total implementation costs	$9,697,000
Total implementation costs (with contingency)	$10,997,000
Total implementation cost per subscriber at 60% take rate	$6,509

The primary hubsite is placed at a County-owned facility, White Rock Fire Station #3, along the existing middle-mile connection between White Rock and the Townsite in order to take advantage of County-owned fibers along that route (see Figure 47). The County also owns an estimated 1.2 miles of existing conduit in the White Rock area that overlaps with the FTTP design, as shown in Figure 48. Use of this conduit would save $229,740. These savings have been included in the cost estimate.

Figure 48: Areas of existing conduit overlap with Model B

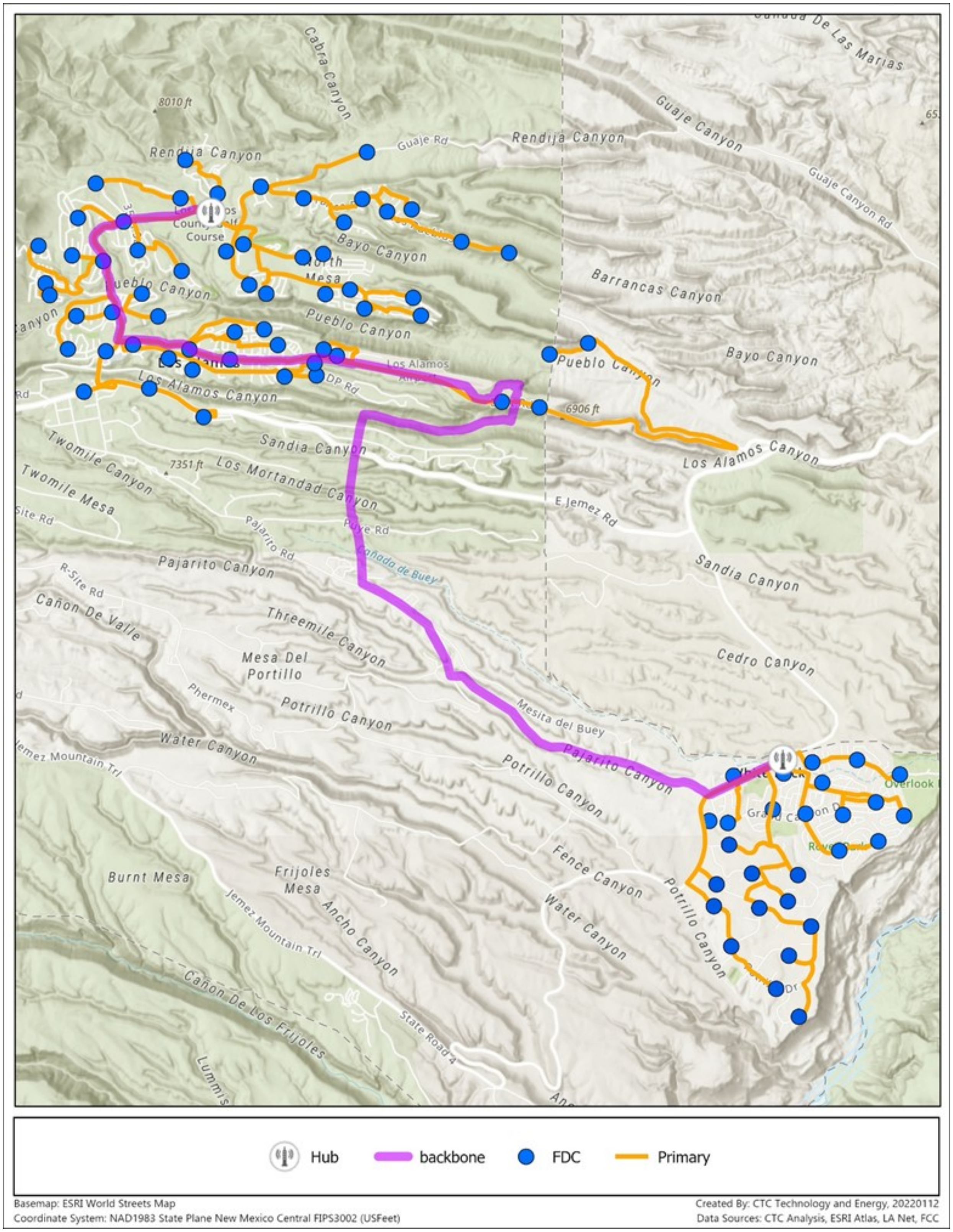


ATTACHMENT B

6.3.3 Models A and B combined

This model assumes that both White Rock and Townsite will be built out and connected via the existing County-owned middle-mile fiber between the two areas (see Figure 49). The combined design would feature two network hub locations, 84 total fiber distribution cabinets, and 157 miles of fiber plant.

Figure 49: Townsite and White Rock combined design overview



ATTACHMENT B

The backbone and distribution plant for Models A and B combined is estimated to cost $26.6 million, or $2,650 per passing, including a 20 percent contingency cost on construction material. These costs are itemized below in Table 22. Note that the costs have been rounded.

Table 22: Estimated fixed costs for Models A and B combined

Cost element	Cost
Project management	$900,000
Engineering and as-builts	$1,650,000
Conduit and vault infrastructure	$12,950,000
Materials	$1,900,000
Labor	$11,050,000
Aerial strand	$650,000
Materials	$150,000
Labor	$500,000
Utility pole make-ready	$800,000
Fiber optic cables and components	$2,750,000
Materials	$1,900,000
Labor	$850,000
Fiber splicing, testing, and documentation	$700,000
Hub facilities and systems	$900,000
Core network electronics	$1,500,000
Distribution plant total cost	**$22,800,000**
Post-Covid-19 market demand contingency on construction material (20%)	$3,750,000
Distribution plant total cost with contingency	**$26,550,000**
Number of passings	10,014
Cost per passing	**$2,650**

Table 23 presents the estimated costs for FTTP distribution electronics, subscriber drops, and CPE. As not all addresses will choose to sign up for service, we have estimated a take-rate of 60 percent.

Table 23: Estimated distribution network electronics, subscriber drop, and CPE costs for Models A & B combined

Cost element	Cost
Number of subscribers	6008
FTTP distribution network electronics	$1,200,000
Subscriber drop costs (including MDU wiring)	$3,400,000
Customer premises equipment (ONT/router)	$2,800,000
Total cost	**$7,400,000**
Cost per subscriber	**$1,232**

Table 24 presents the estimated total implementation costs for Models A and B combined, assuming a 60 percent take-rate. The total implementation cost is estimated to be $30.2 million. The total implementation cost with a 20 percent contingency on construction material is estimated to be $34 million, or $5,650 per subscriber.

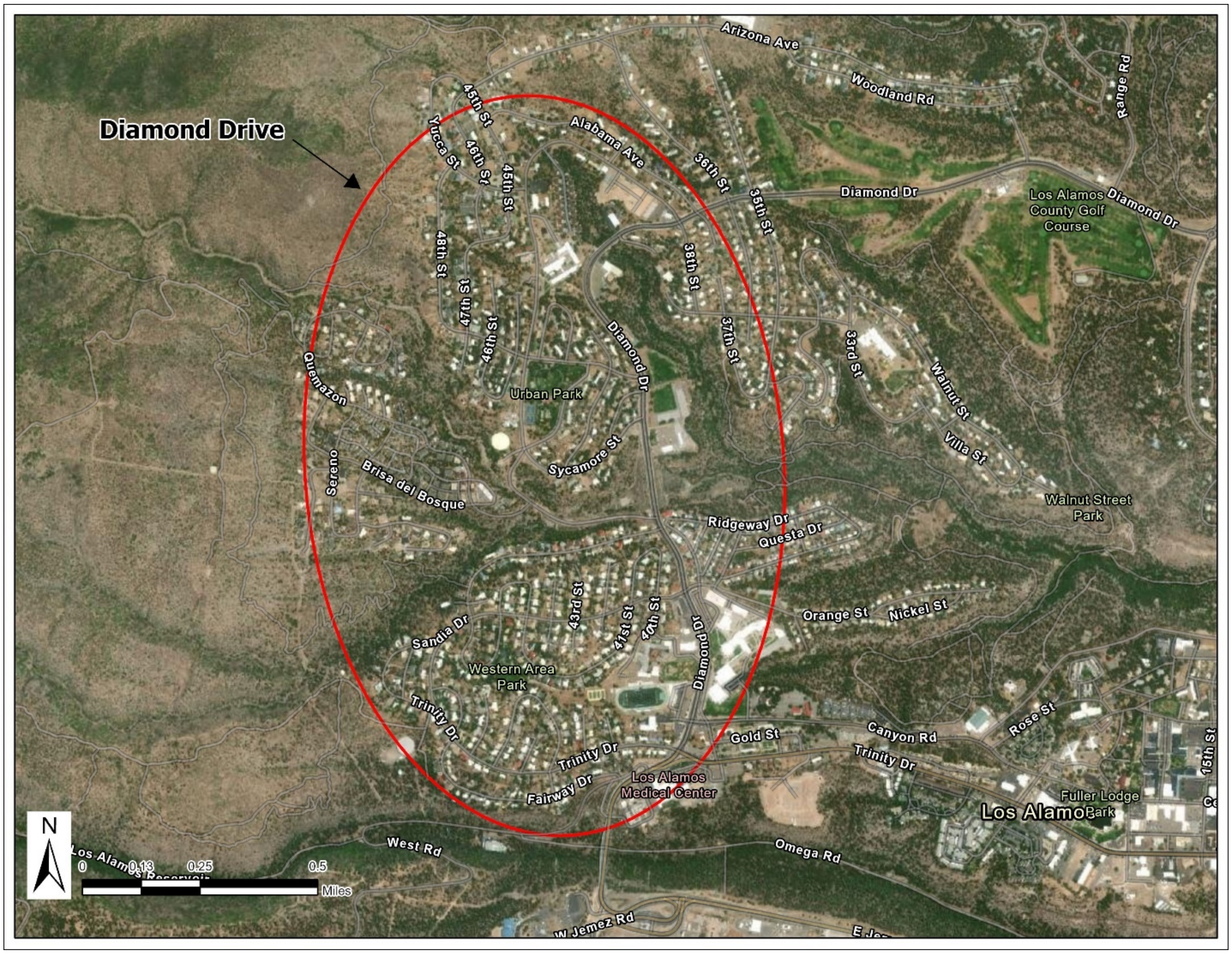
Table 24: Estimated total implementation costs for Models A and B combined

Cost element	Cost
Total implementation costs	$30,200,000
Total implementation costs (with contingency)	$33,950,000
Total implementation cost per subscriber at 60% take rate	$5,650

6.3.4 Additional potential savings (Diamond Drive reclamation area)

The Diamond Drive reclamation area in Northeast Los Alamos could also provide potential cost savings for Model A (Townsite). The County reports that at the time of reconstruction as many as two additional conduits were installed to every household for future use. The County estimates that at least 80 percent or more of this conduit is viable and available for use. Figure 50 below shows the reclamation area.

Figure 50: Diamond Drive reclamation area



ATTACHMENT B

7 Potential business models

See Attachment A Presentation.

8 Funding opportunities

See Attachment A Presentation.

Appendix A: Technology comparative analysis

This report presents an overview of current and emerging internet access technologies (wired and wireless) that could play a role in sustainable, scalable solutions for filling gaps in Los Alamos County's unserved and underserved areas.

The quality and speed of an internet connection will vary based on the capacity and limitations of the last-mile technology used. For purposes of capacity, reliability, and scalability, fiber-to-the-premises (FTTP) is superior to all other fixed broadband technologies. FTTP is superior in capacity to even the best of all theoretical wireless technologies.

The unrivaled transmission capacity of optical fibers, combined with a projected lifespan that far exceeds 30 years, makes construction of fiber optic infrastructure essentially a future-proof investment that will meet users' current and next-generation requirements.

In contrast to other wired and wireless transmission technologies, fiber has low operations and maintenance costs. The medium is practically immune to environmental factors such as material corrosion, lightning, or radio wave interference that commonly impact conventional coaxial cable, twisted-pair copper, and wireless transmission systems.

Unfortunately, due to its high capital costs, fiber infrastructure is not ubiquitously available, particularly in areas that are less densely populated. In Los Alamos County, hybrid fiber-coaxial (HFC) cable networks are more prevalent because they developed from the widely deployed cable television networks. As cable providers upgrade their networks by replacing coaxial cable with fiber, those networks are able to scale to broadband speeds that can rival fiber in some scenarios.

For areas that lack fiber and HFC network coverage, wireless communications may potentially be suitable for filling broadband service gaps. While wireless solutions have limitations in terms of bandwidth and reach, the technologies continue to evolve—as exemplified by the proliferation of broadband mobile service. Furthermore, in addition to terrestrial-based fixed wireless network access, new concepts of satellite communications and flying platforms that are in later phases of development or even at early stages of test deployments could become viable communications vehicles for communities where fiber construction is and will remain cost prohibitive.

Wireless connectivity may even be contemplated as a substitute for fiber where the cost of constructing fiber is deemed too high (although analysis of upfront capital costs and long-term operating expenses is required to evaluate the business case for either investment). A wireless implementation also requires a timeline that typically is much shorter than new fiber construction.

Fiber-to-the-premises (FTTP)

Fiber optic cables are the medium of choice for data transfer. They have enormous bandwidth capacity, which enables operators to offer symmetrical download and upload speeds. Fiber is also not subject to interference and does not require amplifiers to carry a signal over long distances.[31] This is why the vast majority of the internet backbone is comprised of bundles of fiber cable strands.

Once a location is connected to fiber, there is no need for significant outside plant infrastructure investment for decades. If more bandwidth is needed, the operator need only upgrade the network electronics, rather than having to replace the cables.

The electronics needed to provide 1 Gbps speed over a fiber-to-the-premises (FTTP) network are already widely available at an affordable price, and the price of the electronics needed to support 10 Gbps connections are declining rapidly.

Technical capacity and limitations

Fiber is one of the few technologies that can legitimately be referred to as "future-proof," meaning that it will be able to provide customers with better and faster service offerings to accommodate growing demand.

The biggest advantage that fiber offers is bandwidth. A strand of standard single-mode fiber optic cable has a theoretical physical capacity in excess of 10,000 GHz,[32] far in excess of the entire wireless spectrum combined, and thousands of times the capacity of any other type of wired medium, which can be symmetrically allocated between upstream and downstream data flows using off-the-shelf technology.

Further, modern fiber can provide extremely low signal loss within a wide range of frequencies, or wavelengths, of transmitted optical signals, enabling long-range transmissions. Compared to a signal loss on the order of tens of decibels (dB) over hundreds of feet of coaxial cable, a fiber optic cable can carry a signal of equivalent capacity over several miles, without amplification, and with minimal signal loss.

Moreover, weather and environmental conditions do not cause fiber cables to corrode over time in the way that metallic components can, which means that fiber has lower maintenance costs.

Factors impacting quality and speed of service

The following factors will determine an FTTP customer's service speed and quality:

[31] Maximum distances depend on specific electronics—six to 25 miles is typical for fiber optic access networks.
[32] Conservative estimate derived from the channel widths of the 1285 to 1330 nm and 1525 to 1575 nm bands in G.652 industry-standard single-mode fiber optics.

- **Network electronics:** Core equipment in an FTTP network is housed at a central office (CO) or video headend office (VHO). If a housing developer builds an FTTP network, core equipment can be placed in a central telecommunications room or closet in a building or in a campus.
- **Network architecture:** Some FTTP operators use passive optical network (PON) technology, splitting the fiber capacity in a neighborhood cabinet to connect up to 64 users. This architecture provides less capacity per user than a direct fiber network (also known as active Ethernet or point-to-point) but is still able to provide 1 Gbps to users. Currently deployed PON networks have a shared capacity of 2.5 Gbps/622 Mbps (GPON) or 10 Gbps/2.5 Gbps (10GPON).

Future capacity and lifespan of investment

Using off-the-shelf electronics, an FTTP network can deliver speeds well in excess of what most customers need today, and service providers can continue to upgrade network electronics to offer improved tiers of service. The outside plant can last for decades with minimal maintenance.

Hybrid fiber-coaxial (HFC)

Hybrid fiber-coaxial (HFC) cable networks utilize both optical fiber and coaxial cable. Coaxial cables were originally designed to provide video services, and HFC networks with fiber built within a half-mile or mile of the home were sufficient in the early years of data communications. However, as demand for data capacity increased, those HFC networks became insufficient to support high-speed services. On an increasingly large scale, cable operators are now deploying fiber into their networks (i.e., replacing coaxial with fiber)—and those operators' new broadband deployments are fiber-to-the-premises. Today, many cable operators choose to build FTTP for so-called "greenfield" builds, where extending service into a new area requires new construction and there are few advantages in extending the coaxial part of the network.

HFC system configurations vary but in many cases will utilize a fiber backbone network that carries data from providers and their broadband equipment to fiber distribution nodes scattered throughout a service provider's area. From there the signal spans the last fraction of a mile via coaxial cables before reaching its destination at a residence or business.

One of the downsides of HFC, especially in comparison to technologies such as fiber optic, is that network performance is dependent on the most limited part of the network. In this case, the coaxial cable is the limiting factor in an HFC network. A single fiber strand has over 10,000 times the capacity of a coaxial cable, and a typical fiber cable has dozens or hundreds of strands. It is also much more prone to electromagnetic interference, signal loss, power failures,[33] lightning strikes, and equipment failures and a has a higher security risk than fiber. As a result of these performance factors and the relative resilience of all fiber network components, FTTP has lower operating expenditures than that of HFC networks

Technical capacity and limitations

Although there are a number of significant limitations inherent in cable systems relative to fully fiber optic networks, cable system capabilities will increase over the next few years with the deployment of new technologies and the extension of fiber closer to customers.[34]

In an HFC network, headend or hub locations house the core transmission equipment. Fiber connections extend from these hubs to multiple nodes, each of which serves a given geographical area (e.g., a neighborhood). These optical nodes are electronic devices located outdoors, attached to aerial utility lines or placed in pedestals. The equipment in the node converts the optical signals carried on fiber into electronic signals carried over coaxial cables. Coaxial cable then carries the video, data, and telephony services to individual customer locations.

Cable operators have extended fiber optics progressively closer to their subscribers, but for cost reasons have generally stopped at nodes about one mile from the premises. Comcast, for example, typically only constructs fiber to the premises of customers that subscribe to Metro Ethernet and other advanced services.

It is critical to note that these are peak speeds, and that the capacity is shared by all customers—typically hundreds of homes or businesses—on a particular segment of coaxial cable. Speeds may decrease during bandwidth "rush hours," when more users simultaneously use greater amounts of bandwidth. For example, residential bandwidth use typically goes up considerably during evening hours, when more people use streaming video services and other large data applications.

Factors impacting quality and speed of service

The following factors will determine a cable broadband customer's service speed and quality:

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[33] The coaxial portion of an HFC network requires power insertion roughly every mile. Most HFC networks have backup power only for a few hours. In contrast, fiber passive optical networks have power inserted at the wire center or central office, each of which can serve tens of thousands of addresses and host generators that can run indefinitely with refueling. As a result, HFC networks are especially vulnerable to long-term power outages.

[34] Cable is not as scalable "out of the box" as communications systems that were designed from the outset to provide internet-type broadband data services. Issues include coaxial cable's limitations in terms of physical capacity, a physical architecture optimized for broadcast communications, and a significant remaining migration path to full end-to-end Internet Protocol (IP) operations.

1. **Bandwidth capacity of cable plant:** Most coaxial portions of a cable network have capacity of 750 or 860 MHz, but they can be upgraded to 1 GHz and beyond. If the cable corrodes, the available bandwidth shrinks, limiting possible connection speed.

2. **Number of customers sharing a node:** Cable capacity is shared among all the users connected to a given node, so connection speeds will decrease significantly during peak usage hours. Cable companies can reduce the number of customers sharing a node by putting fiber deeper into their systems and moving the node closer to the customers.

3. **Proximity of customer to node/fiber:** Another advantage of moving the node closer to the customer is that signals travel less distance on coaxial cable. With progressively shorter stretches of coaxial cable, the inherent problems with reliability and interference decrease.

4. **Standards and protocols:** Cable operators can make faster connection speeds available by dedicating more channels to data services and upgrading their networks to later versions of industry standards. State of the art DOCSIS 3.1 technology that is now in most networks makes more efficient use of available spectrum, freeing up more bandwidth for data download and upload.

Cable operators often offer services with “blast” or “burst” speeds of “up to” more than 100 Mbps. Although a customer may be able to access these speeds on occasion, the actual speeds will probably be significantly lower during peak usage hours.

Digital subscriber line (DSL)

Digital subscriber line (DSL) technology uses copper telephone lines. DSL was a retrofit of copper telephone infrastructure that began in the 1990s. While this was a relatively cost-effective means of getting value from the infrastructure relative to other wireline broadband technologies, DSL is the most limited technology.

DSL operates by using digital modems that use wide, frequency spectrum bands relative to dial-up phone lines and therefore have up to a thousand times more capacity than a single phone line.

Because interference can enter the copper lines, DSL typically require DSL filters to “clean up” the signal on the lines. There are two primary types of DSL that exist today. Asymmetric digital subscriber line (ADSL) and very high-speed digital subscriber lines (VDSL). ADSL is in older networks and can operate over copper lines up to about three miles in length.

VDSL operates at higher bit rates than ADSL. This is because it uses even higher frequencies and larger channel bandwidths than ADSL. The trade-off, however, is that the high frequencies cannot operate over distances as long as ADSL, so VDSL is typically limited to less than one mile, requiring fiber to be built from telephone central offices to neighborhood cabinets, or nodes.

Therefore, with shorter copper line distances, DSL operators can offer speeds that fit the FCC's definition of broadband of 25/3 Mbps. However, for providers using Digital Subscriber Line (DSL) technologies to offer speeds at 25/3 Mbps or greater, the maximum buffer is a distance of 6,600 route feet from the cabinet to the covered premises.[35]

It is unclear what level of adherence to this standard currently exists as it requires service providers to divulge cabling distances, cabinet locations, and serviced customer premises addresses. It is also unreliable to use the linear distance between DSLAM locations and customer locations to determine cable lengths as the cables are almost certainly not routed in linear fashion to consumers. Conduit carrying this cable often traverses many twists and turns on the way to reaching the customer's premises equipment. It is highly likely that cable could be routed in a very inefficient manner. Based on these concerns, there are likely DSLAMs located over 6,600 routed feet from the customer location. The "served" status of many of the DSL-only locations on the current government maps are therefore likely to fall short of the speeds that are advertised by the service providers.

Technical capacity and limitations

Bandwidth limits on copper cables are directly related to the underlying physical properties of the medium. Higher data rates require a broader frequency range of operation. Twisted-pair copper wire is limited to a few tens of megahertz in usable bandwidth, at most, with dramatic signal loss increasing with distance at higher frequencies.

The main determinant of DSL speed is the length of the copper line from the telephone company central office. In systems operated by large telecommunications companies, the average length is 10,000 feet, corresponding to available DSL speeds between 1.5 Mbps and 6 Mbps. In systems operated by small companies in rural areas, the average length is 20,000 feet, corresponding to maximum speeds below 1.5 Mbps.

The fastest copper telephone line technologies widely deployed in outside cable plant in the United States are VDSL and VDSL-2, the technologies underlying AT&T's U-verse and other services. Because these technologies use high frequencies, they are limited to 3,000 feet over typical copper lines and require fiber to the node (FTTN)—much closer than in most HFC systems. Therefore, in order to operate VDSL and VDSL-2, telecommunications companies must invest in large-scale fiber optic construction and install remote cabinets in each neighborhood.

[35] Data Specifications for Biannual Submission of Subscription, Availability, and Supporting Data - March 4, 2022. http://www.fcc.gov/sites/default/files/bdc-availability-data-specifications-03042022.pdf (fcc.gov)

In practice, telephone companies using VDSL-2 over highly upgraded copper lines have been able to provide 25 Mbps over a single copper pair and 45 Mbps over two pairs to the home or business—but it took a significant investment to make it possible for a small percentage of the copper phone lines to temporarily keep pace with cable. Providing even greater speeds will require some combination of even deeper fiber construction, a breakthrough in transmission technology over copper lines, and conditioning and upgrading of the existing copper lines.

The Alcatel-Lucent G.Fast DSL product in development has reached speeds of 500 to 800 Mbps in various environments—but it is limited to 330 feet, requiring the construction of fiber to the curb in front of each home or business—an investment that would be comparable to building a FTTP network.[36] As a result, G.Fast has so far mostly been focused on deployments using telephone wires inside apartment or office buildings—for example, by a provider that brings fiber to the building or high-speed wireless to a rooftop, and then places G.Fast electronics on the copper to extend that service to individual apartments or offices.

Factors impacting quality and speed of service

The following factors will determine a DSL customer's service speed and quality:

- **Length of copper line/proximity to fiber:** The longer a signal travels over copper cable, the slower the potential connection speed.
- **Condition of copper cable:** Copper cable corrodes over time. As it deteriorates, interference increases and the available bandwidth shrinks, limiting the potential connection speed.
- **Number of copper pairs available:** To overcome the inherent limits of copper cable, some operators bundle multiple copper pairs.

Future capacity and lifespan of investment

It is only a matter of time before the growing demand for bandwidth comes up against the physical limitations of copper as a medium for transporting data. Even if an operator can satisfy present demand using existing copper assets, it is a significant challenge to upgrade a DSL network in a way that the majority of a large-scale network can continue to serve future demand. Many telecommunications companies are minimizing their investment in copper lines, and some are abandoning copper lines for wireless services or migrating to FTTP. New investment in DSL will likely become obsolete within a decade.

[36] Mikael Ricknas, "Alcatel-Lucent gives DSL networks a gigabit boost," *PC World*, July 2, 2013, http://www.pcworld.com/article/2043483/alcatellucent-gives-dsl-networks-a-gigabit-boost.html.

Fixed wireless

The high cost of building wired networks in low-density rural areas often leaves rural residents without a wired broadband option. Wireless internet service providers (WISPs) are potentially able to fill these coverage gaps, sending signals from base stations to antennas on or near customer premises. But WISPs are not able to offer connection speeds on a market-wide basis comparable to cable or FTTP built to each premises, and often need to impose data caps on customers to manage limitations on capacity. Accordingly, although fixed wireless service is an important tool to help connect the unconnected, most fixed wireless solutions will not offer the quality of service that the most advanced wired providers can provide. Even as wireless technologies continue to advance, they will still lag behind the performance of fiber optics, simply because of the relative challenge in providing high-capacity connections wirelessly over long distances.[37]

Technical capacity and limitations

Smaller WISPs use the same unlicensed spectrum bands as Wi-Fi, which does not have strong long-distance transmission qualities. (This is in contrast to the large mobile carriers like AT&T, Sprint, T-Mobile, and Verizon Wireless, which offer 3G/4G service using licensed spectrum.) WISPs may also use other unlicensed or semi-licensed bands like 3.5 GHz CBRS or 900 MHz, but these also have low data speed capabilities. There are also providers, especially in urban areas, who are using advanced millimeter wave wireless technologies. These potentially provide speeds of 1 Gbps over a link, and providers such as MonkeyBrains and Starry have created networks in Boston, San Francisco, and elsewhere that send signals from rooftop to rooftop and distribute the service indoors with a combination of existing copper cabling and Wi-Fi.

Most wireless networking solutions require the antenna at the customer premises to be in the line of sight of the base station antenna. This can be especially challenging in mountainous regions. It is also a problem in areas with dense vegetation or multiple tall buildings. WISPs often need to lease space at or near the tops of radio towers; even then, some customers may be unreachable without the use of additional repeaters. And because the signal is being sent through the air, climate conditions like rain and fog can impact the quality of service.

Some wireless providers in rural areas have begun to use vacant television frequencies called TV white space (or simply white space) to provide service. These TV bands have much better non-line-of-sight transmission qualities than the unlicensed bands; however, because white space technology is still in an early phase of development, compatible equipment is far more expensive than other off-the-shelf wireless equipment.

[37] The analysis of wireless options presented in this report assumes a benchmark capacity of 1 Gbps per location. That is not to say that lower bitrate systems may be insufficient for some locations, nor would it suggest that higher bitrates would not be desirable for others at some time in the future.

Wireless equipment vendors offer a variety of point-to-multipoint and point-to-point solutions. Point-to-multipoint solutions are more affordable to implement and are typically used in a WISP environment. However, they limit the capacity of the network, particularly in the upstream, making the service inadequate for applications that require high-bandwidth connections.

Fixed wireless systems built with off-the-shelf equipment today tend to have an aggregate capacity between 100 and 250 Mbps. With innovations like higher-order multiple input, multiple output (MIMO) antennas, and the use of spatial multiplexing, these capacities will likely increase across vendors to as fast as 750 Mbps. It is important to note, however, that this is the aggregate capacity; bandwidth will be shared among up to 200 users connected to a single base station.

Factors impacting quality and speed of service

The following factors will determine a fixed wireless customer's service speed and quality:

- **Wireless equipment used:** Different wireless equipment has different aggregate bandwidth capacity and uses a range of different spectrum bands, each with its own unique transmission capabilities.
- **Backhaul connection**: Although the bottleneck tends to be in the last-mile connection, if a WISP cannot get an adequate connection back to the internet from the tower, equipment upgrades will not be able to increase available speeds beyond a certain point.
- **Unobstructed line of sight:** Most wireless networking equipment requires a clear, or nearly clear, line of sight between antennas for optimum performance. WISPs often lease space near the tops of radio towers in order to cover the maximum number of premises with each base station. In mountainous regions, many premises may not have a clear line of sight to a radio tower.
- **Weather conditions and foliage:** Depending on the spectrum used, weather conditions like rain or fog may cause interference. Also, line-of-sight paths that are clear during the winter may be obstructed by foliage during the warmer months.

Future capacity and lifespan of investment

Wireless equipment generally requires replacement every five to 10 years, both because exposure to the elements causes deterioration, and because the technology continues to advance at a rapid pace, making equipment from a decade ago mostly obsolete. The cost of deploying a wireless network is generally much lower than deploying a wired network, but the wireless network will require more regular investment.

Satellite-based communications

Satellite-based communication, facilitated by geostationary (GEO) and low earth orbiting (LEO) satellites, provides the distinct advantage over terrestrial communication of nearly ubiquitous coverage of a large area of up to thousands of square miles. For GEO satellites, the high altitude allows a few satellites to cover very large areas, while for LEO satellites, thousands of small satellites achieve similar effects. The mostly unencumbered line of sight with the satellite—apart from local obstructions by vegetation or built structures—means signal loss is low. The large distance between transmitter and receiver for GEO systems introduces time lags that hamper real-time applications such as video, but LEO systems can theoretically support mobile broadband – although this technology is still in early stages of development.

Overview of technology and service providers

Satellite communications via geostationary platforms has been offered for years by several companies in North America, most notably by Viasat, HughesNet, and Telesat. Their satellites are positioned at a distance of 36,000 kilometers from earth, orbiting in synchronization with the earth's rotation. The high altitudes provide the ability for coast-to-coast coverage with one or a few satellites.

Viasat, for example, has two satellites in orbit to blanket the U.S. While the service availability is claimed to be nearly ubiquitous with some caveats based on geography, the available data rate is typically in the sub-hundred Mbps range due to the large number of customer access points the satellite serves and because of the fixed capacity of the transponder electronics in space. A drawback shared by all geostationary communication is the high signal latency, which is approximately 330 milliseconds. Typical data-only applications are not impacted by the delay as much as interactive services or voice communication.

Typical data rates from geostationary satellites range in tiers from 18 Mbps to 100 Mbps downstream and 3 Mbps upstream. The availability of the higher speed tiers is dependent on the subscriber location. In areas of high take-rates (i.e., many subscribers) the user experience tends to be diminished.

In contrast to GEO, LEO satellites have a much-improved broadband potential. As their orbits are at an altitude of 500 km to 650 km, signal delays are an order of magnitude shorter. More importantly, the signal path loss is drastically reduced, allowing greater spectral efficiency—in other words, more data capacity for a given amount of spectrum. Due to the lower orbits, LEO systems provide a smaller wireless coverage area on earth. Unlike geostationary systems that are bound to an equatorial path, LEO constellations can orbit the earth in any direction, thereby forming a contiguous stellar communications network. But because LEO satellites travel at a faster angular speed than the earth's rotation, more satellite stations are required to guarantee continuous connectivity on the ground as the ground receiver is handed off to the next closest satellite.

LEO systems have been in use since 1997 when Iridium launched 66 satellites that have been providing voice and low-speed data service worldwide to handheld devices. The LEO concept has gained renewed and significant momentum in recent years with new entrants that put forward ambitious projects, such as SpaceX with its Starlink program, which started operations in 2019. Further contenders include, among others, the British company OneWeb; Amazon's Kuiper project, which is scheduled to launch in 2023, and Telesat's Lightspeed, projected to go live in 2025.

Starlink currently has more than 3,000 satellites in operation. The company has also received FCC approval for an additional 7,500 satellites in coming years for a total of around 42,000 satellites by mid-2027.[38] With every launch of 60 satellites, the aggregate data capacity is augmented by 1 Tbps. [39]

Residential and small business customers signing up for Starlink service today may receive data speeds of 100 to 150 Mbps downstream and 20 to 40 Mbps upstream. In rarer cases, speeds exceeding 400 Mbps have been measured. The company has stated that its goal is to increase the data rate to 1 Gbps for residential use, although required technologies enabling those bitrates are still in the development and testing phase.

Starlink's Premium service is expected to have higher throughput and allow multiple concurrent sessions. One use case mentioned by Starlink is internet access at community centers or libraries in underserved regions supporting as many as 40 to 60 concurrent users.

The aggregate bandwidth on the subscriber side is undetermined at this time but expected to be on the order of 500 Mbps downstream. Another model is for Starlink to serve as an infrastructure that internet service providers can use – along with terrestrial services,[40] so future arrangements for internetworking Starlink-connected sites with private residents and/or public entities within a rural community may be a possibility, but is only conceptual at this point.

[38] https://techfundingnews.com/elon-musks-spacex-to-raise-750m-at-137b-valuation%EF%BF%BC/
[39] Interview with Rebecca Hunter, Account Manager at SpaceX, private discussion, February 14, 2022.
[40] Rebecca Hunter interview.

Starlink's residential service is priced at $110 per month and requires the purchase of the antenna and customer premises equipment—for which Starlink charges $599[41], although the equipment has a reported manufacturing cost of $1,000.

Starlink's Premium service subscription is currently priced at $500 per month. The customer premises equipment, including antenna, has a price tag of $2,500.

An interesting use case is for LEO systems such as Starlink to provide direct cellular connectivity to connect to cellphones in areas that are currently dead zones. Unlike the very expensive edge equipment and subscription costs, this would not require any additional equipment beyond existing cell phones as mobile partner providers use existing spectrum they own for this capability. T-Mobile has partnered with Starlink, but Verizon and AT&T have announced similar initiatives with other LEO partners, AT&T with AST SpaceMobile, and Verizon with Kuiper.[42]

Though LEO systems are promising they face substantial challenges. LEO systems require thousands of satellites. It is not clear that the market is strong or large enough to fund that investment. Even small divergences on expectations of lifespan of the equipment could make enormous differences in financial viability. In short, the biggest problems right now are:

- It is unclear that LEO systems can sustain promised speeds as more customers join the network because there are capacity constraints per satellite and per earth base station.
- There is no indication that the proprietary and expensive customer edge equipment will come down in price. So far, it has increased in price – without industry standards and scale, prices are unlikely to go down.
- There is no indication that the very high cost of monthly subscription will go down in price. So far, it has increased from its initial $99 to $110 per month, and the equipment fee has gone up $100. Starlink has so far pushed back against any efforts to define a more affordable, lower bandwidth pricing tier and does not participate in the federal Affordable Connectivity Program.
- There is no guarantee that the network is sustainable in the long run. It is extremely costly to deploy and maintain, and Starlink is facing competition from other LEO entrants and mobile and fixed broadband providers. Any investment in Starlink equipment and service now may not be of any use a few years from now.

[41] https://www.satelliteinternet.com/providers/starlink/

[42] https://www.fiercewireless.com/wireless/podcast-rounding-year-telecom, https://www.bloomberg.com/news/articles/2022-10-05/at-t-ceo-says-his-satellite-phone-service-has-lead-over-musk-s).

Middle-mile in the sky

Telesat, a Canadian satellite operator of 15 geostationary satellites with yearly revenue of $700 million, is working on Lightspeed, a LEOS-based service with an investment of $5 billion and plans to be operational by 2025. Unlike Starlink and Kuiper, which primarily serve the residential and small business markets, Lightspeed is targeting enterprise customers with data rate requirements from 100 Mbps guaranteed bandwidth to gigabit speeds with carrier-grade availability. Their service is strictly based on a layer 2 connection model in line with a Metro-Ethernet type private network service. In addition, Telesat plans interconnection options with major data centers and carrier connection exchange points. In that role within the communications market, Lightspeed is the equivalent of a middle-mile fiber provider in the sky providing lit point-to-point and point-to-multipoint services, although with lower capacity.

The first 78 Telesat LEOS will be launched into polar orbits to provide coverage of the northern American continent. Ultimately a constellation of 298 satellites with a total capacity of 15 Tbps transmitting in the KA band (26 to 40 GHz) with beam forming antennas will provide what the company calls seamless connectivity to its customers. The company claims high service availability will be achieved through redundancy with inter-satellite free-space optic links. At any given time, end users' antennas will have at least two satellites in sight, which the company says will translate to an estimated service availability of 99.999 percent.

The customer site will require a 1-meter-diameter satellite tracking dish antenna for a 100 Mbps symmetrical link; 1 Gbps data rates are possible with antennas of 2.4-meter diameter. Satellite communications systems are notoriously expensive; the smaller antenna system will be available at an introductory price of $10,000, while the larger antenna may be as high as $200,000. Telesat estimates that the prices will be drastically reduced once the service gains traction and the antennas and electronics can be produced in large quantities.

The cost of Telesat's service is currently undisclosed. Prices reportedly will vary by sales volume, location, and contract terms. However, Telesat predicts that the cost per megabit will be orders of magnitude lower than the geostationary communication services pricing. On the other hand, Telesat also states very clearly that they do not intend to compete with fiber providers and that they will not be able to match the price of fiber-based services.[43]

At this point, the federal government of Canada is the first and only contracted customer for Lightspeed service.

One can speculate that Starlink, with a fully populated constellation of 12,000 satellites—which the company says will grow to 30,000 spacecraft with a capacity of about 17 Tbps per satellite—

[43] Jeffrey Gardiner, Director of Sales, Telesat, private communication, February 14, 2022.

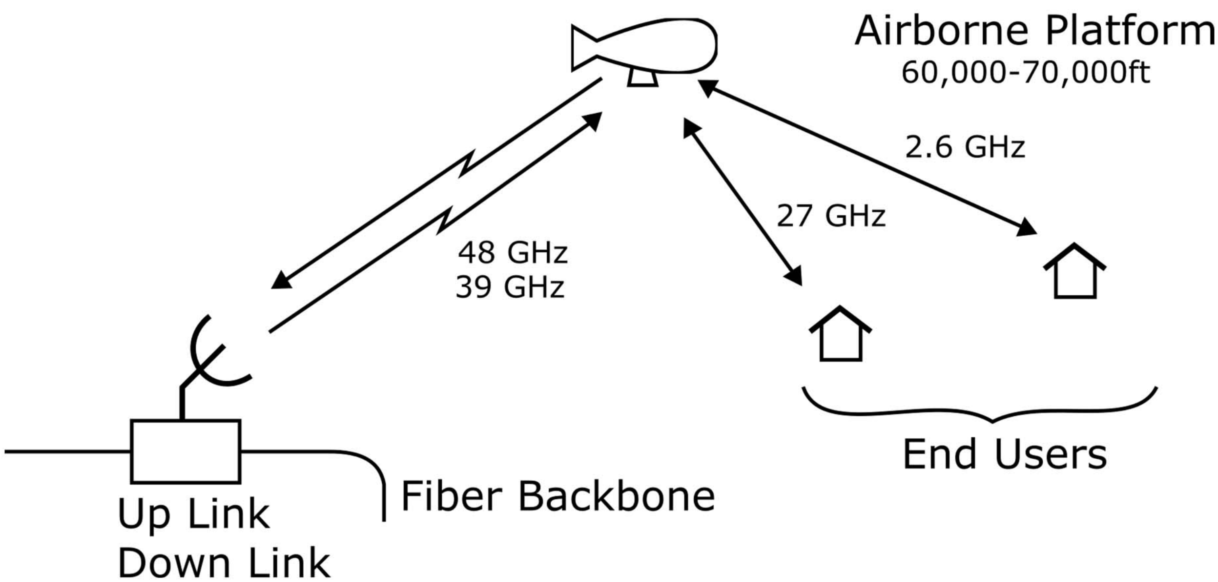
will have sufficient bandwidth to entertain different service models (including wireless backhaul with connection speeds exceeding 1 Gbps). When asked about that prospect, a representative of Starlink did not rule out such service plans but was reticent about sharing any vision for the company's plans beyond the Premium service.

High-altitude platform systems

In light of the high capital investments and operations costs of satellite communications, the concept of lower-cost high-altitude platform systems (HAPS) has gained much attention in the communications community in recent years.

HAPS are quasi-stationary airborne communications platforms in the stratosphere outside the commercial traffic airspace between 60,000 feet and 70,000 feet (Figure 51). That altitude appears to be particularly suitable for the positioning of aircraft as atmospheric turbulence is rare and average wind speeds are light (5 mph to 40 mph). Air movement is somewhat dependent on the region with lower latitudes typically exhibiting less air movement.

Figure 51: HAPS concept of a wireless communications tower in the sky



Compared to LEOS service the transmitters on HAPS are much closer to the end user, thus reducing the latency to a range comparable to terrestrial wireless communication and allowing for better signal strengths between earth and aircraft. The most significant advantages of HAPS over terrestrial and satellite communications cited by industry experts include:

- Capital investment and cost of operations is expected to be drastically lower for HAPS than for satellite systems.

- HAPS provide flexibility in serving remote areas and in filling terrestrial wireless coverage gaps (white spots).
- Services provided from HAPS may be possible with off-the-shelf customer equipment.
- Signal latency from HAPS platforms of approximately 0.3 milliseconds is comparable to terrestrial wireless communication and therefore suitable for voice communication and interactive applications.
- HAPS have a short deployment time: HAPS can be brought into position within hours, which may be in high demand in disaster recovery scenarios.
- Easy payload and transponder customization allow HAPS to support a variety of service models, including backhaul service.

HAPS concepts are currently in a research and development phase. The idea of using flying platforms for communications purposes dates back to 1996 when the ITU initiated a use case study. The practical exploration and development of suitable prototypes started much later in 2011, when Google launched its balloon-based version of a HAPS, called Loon LLC. Many approaches to HAPS have been envisioned and prototyped since then.

Experimental HAPS have been implemented in the forms of fixed-wing lightweight drones powered by solar cells and blimps of various sizes. The list of stakeholders and participants in HAPS projects today includes well-known names in the communications industry (Google, Facebook, Deutsche Telecom) and aircraft industry (Airbus), among many others, which is evidence of the broad interest in airborne communications platforms.

Most of the ongoing testing has the primary goal of finalizing a design of unstaffed communications aircraft that have the capability to stay aloft for weeks or months, to maintain the desired position, and to be safely returned to earth for maintenance. Several projects initiated in early years have been terminated as the experiments did not yield the results required for practical high-altitude internet platforms. Google's Loon project was eventually terminated after six years when it was concluded that the balloons' positioning by means of altitude control was not feasible. Aquila, launched by Facebook in 2016, was also cancelled just two years later after a failed flight test landing exposed both design and control flaws.

Much of current development efforts of high-altitude flying platforms seem to be focused on aircraft designs, materials, vehicle control algorithms, and the challenging power management associated with solar cell fueled motors. Some contenders are further along than others. In late 2021, Airbus's Zephyr concluded a successful test flight of a solar-powered glider with a flight time of 36 days at an altitude of over 70,000 feet. Thales Alenia's Stratobus blimp prototype is taking shape but will not be available before 2024.

Sceye, a company that has concentrated its efforts on blimp technology development, claims to be close to a final prototype that could be put into service by 2024, assuming that the test flights in the next two years validate the expected long-term integrity of the blimp's skin material, solar cell capacity, and the flight control system of the airship.[44] The company has developed and tested nine blimp prototypes in eight years. With every subsequent blimp version, lessons learned from previous tests were incorporated in the aeronautic engineering design, material compositions, and remote and autonomous flight control algorithms.

Sceye estimates that their blimps will be able to hold payloads of several hundred kilograms and stay in designated positions for up to a year before they would have to be returned to ground for maintenance.

[44] Alfredo Serrano, VP Marketing and Sales, Sceye, private communication, February 9, 2022.