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Cost of Bringing Broadband to All

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1. Executive Overview

The United States is experiencing an infusion of funding from federal and state governments to deploy broadband infrastructure and make service available nationwide to all consumers. This funding is in addition to ongoing federal and state universal service programs, which have the complementary goals of both extending and maintaining broadband service. It is imperative to understand the magnitude of the costs of deploying broadband network infrastructure to all to gain a realistic picture of what dollars are necessary to accomplish universal broadband availability. In recent years, several studies have attempted to estimate the cost of deploying broadband networks to all, with wildly varying results. Those studies make differing assumptions about the number of locations to be served and the cost of extending a broadband fiber network to those locations. In Vantage Point Solution's ("VPS") opinion, the conclusions of each study regarding the cost to deploy fiber to the entire country are not reasonable estimates for the following reasons:

1. Several of the studies underestimate the number of locations that lack broadband because they rely on faulty FCC Form 477 data.
2. Several of the studies focus only on the number of locations lacking 25/3 Mbps broadband service availability, and therefore do not address the cost of upgrading locations that are considered "underserved" under the Infrastructure Investment and Jobs Act ("IIJA") because they lack 100/20 Mbps broadband service availability.
3. The studies underestimate the cost per location of deploying fiber. Several rely on cost estimates derived from the FCC's cost model – the Connect America Cost Model – which was developed between 2012 and 2014 using inputs derived from telecom industry data from 2007 to 2010 and do not consider inflation over the last decade. Another study assumes an unrealistically low cost per home passed, relying on data from deployments in areas that are not comparable to most unserved rural markets. Overall, the studies' cost estimates are not consistent with VPS engineering analyses done in 2020 in preparation for the Rural Digital Opportunity Fund ("RDOF") auction. The assumed cost per location in the studies was two to six times lower than the VPS engineering estimates, which averaged $11,000 per location.

VPS estimated the cost to construct fiber to all unserved and underserved locations using real-world experience with engineering deployments in rural markets across the United States, a more realistic estimate of the number of unserved and underserved locations and consideration of inflation. VPS found that the cost could likely exceed $400 billion, which is considerably more than what is planned for all state and federal broadband programs.

2. Introduction

The ongoing COVID-19 pandemic has made nearly every industry, including education, entertainment, commerce, healthcare, and public safety, realize the importance of broadband. The IIJA stated that "access to affordable, reliable, high-speed broadband is essential to full participation in modern life in the United States."[1] In a digital age, both urban and rural consumers must have access to adequate broadband. Congress realized the importance of broadband when it stated that "[t]he persistent 'digital divide' in the United States is a barrier to the economic competitiveness of the United States and equitable distribution of essential public services, including health care and education."[2]

Some assume that the additional funding that Congress has appropriated for broadband infrastructure investment since 2020 will be enough to ensure that everyone in the United States has access to broadband at speeds of 100/20 Mbps or higher. This analysis will assess the validity of that assumption, focusing on the cost of deploying fiber because that is the only technology, in VPS's opinion, that can meet the IIJA's call to scale "over time to meet the evolving connectivity needs of homes and businesses."[3]

In recent years, several entities have attempted to estimate the investment required to provide fiber-to-the-premises ("FTTP") broadband to the entire country. VPS has examined five of those studies: a paper released by Paul de Sa for the Federal Communications Commission ("FCC") in 2017,[4] a study conducted by Boston Consulting Group in 2018,[5] a study conducted by Cartesian in 2019,[6] a study conducted by Cartesian in 2021,[7] and a project undertaken by Tufts University in 2021.[8] In VPS's opinion,

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[1] Infrastructure Investment and Jobs Act, H.R. 3684, 117 Congress Public Law 17-58, Nov. 15, 2021, Section 60101 (1).
[2] Ibid., Section 60101 (2).
[3] Ibid., Section 60102(a)(2)(I).
[4] *Improving the Nation's Digital Infrastructure*, Paul de Sa, Chief, FCC Office of Strategic Planning and Policy Analysis, January 17, 2017 ("de Sa").
[5] *The Economic Case for Bringing Broadband to the Rural US*, The Boston Consulting Group, Wolfgang Bock, Derek Kennedy, Maikel Wilms, Simon Bamberger, and Sam Fatoohi, 2018 ("BCG").
[6] *All-Fiber Deployment Cost Study 2019*, Cartesian, Inc., Sept. 10, 2019.
[7] *Addressing Gaps in Broadband Infrastructure Availability and Service Adoption, A Cost Estimation & Prioritization Framework*, Cartesian, Inc., June 2021 ("Cartesian").
[8] *Turning America's Digital Divide into Digital Dividends*, Digital Planet, The Fletcher School, Tufts University, Institute for Business in the Global Context, July 7, 2021 ("Tufts"). These studies will be referred to in aggregate as the "studies" throughout this paper.

these attempts have significantly understated the cost to deploy broadband networks using fiber. In this paper, we will show that the amount appropriated by Congress is only a fraction of the amount required, relying upon actual VPS engineering analyses done in 2020.[9]

To determine the investment required to deploy ubiquitous broadband across the United States, it is necessary to estimate the number of locations that lack broadband availability and the cost to upgrade these locations to receive the desired level of broadband service. The locations of concern here are places where a customer may subscribe to broadband, which are generally residences and small businesses. In this paper, we will focus on the cost of deploying fiber networks to provide service to residential and small business locations that currently lack broadband. It is worth noting, however, that the IIJA also explicitly recognized the need to provide community anchor institutions with access to gigabit level service.

The number of locations lacking broadband varies depending upon the definition of broadband being used. Although the FCC's current definition of broadband is 25/3 Mbps,[10] many state and federal programs consider 100/20 Mbps to be the minimum standard for broadband.[11] Notably, Congress in the IIJA concluded that locations with less than 100/20 Mbps are "underserved" and locations with less than 25/3 Mbps are "unserved" making such locations eligible for funding.[12] Chairwoman Rosenworcel also recently proposed raising the definition of broadband to 100/20 Mbps and "to set a separate national goal of 1 Gbps/500 Mbps for the future."[13]

In the IIJA, Congress required the National Telecommunications and Information Administration ("NTIA") to utilize the maps developed by the FCC pursuant to the Broadband Data Act when

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[9] The engineering analyses were completed for projects in Alabama, Georgia, Iowa, Illinois, Indiana, Kentucky, Michigan, Missouri, Montana, North Carolina, North Dakota, Oklahoma, Pennsylvania, South Dakota, Texas, and West Virginia.

[10] The nomenclature of 25/3 Mbps means 25 Mbps download and 3 Mbps upload. Similarly, 100/20 Mbps means 100 Mbps download and 20 Mbps upload.

[11] In addition to speed, the minimum broadband standard often includes requirements for reliability, monthly usage allowances, and latency.

[12] Ibid., Section 60102 (a) (C).

[13] Chairwoman Rosenworcel Proposes to Increase Minimum Broadband Speeds and Set Gigabit Future Goal, News Release, (rel. July 15, 2002), DOC-385322A1.

implementing the programs newly created by that law.[14] Until the FCC's mapping effort and related challenge processes for the new data collection are completed, likely not until early 2023 at the earliest, it is impossible to accurately determine the number of locations that lack broadband under the congressional standard.[15]

Without the new broadband availability maps, alternative sources of information must be used to determine the number of unserved and underserved locations. Historically, a primary source used for determining the number of locations that need broadband is the FCC Form 477 ("Form 477"), reported by broadband providers at a census block level. Other private and public sources of information, such as speed test results, have also been used to help estimate the number of unserved locations; however, all these methods have their shortcomings for a variety of reasons:

- Estimation methods based on the Form 477 significantly understate the number of unserved and underserved locations because the FCC considers the entire census block as being served if any single location in that block can receive broadband.
- The number of unserved or underserved locations can increase over time when the broadband definition increases.
- The number of unserved or underserved locations can change as providers expand their broadband networks or as providers exit the business.
- Some locations may not meet the current FCC definition of being a "serviceable location" for reporting purposes and therefore are not counted today yet are increasingly likely to require broadband service.[16]

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[14] In the Broadband Data Act, Congress directed the FCC to develop a granular map of the broadband capability at each serviceable location in the United States. Broadband Deployment Accuracy and Technological Availability (DATA) Act, March 23, 2020, S.1822 (https://www.congress.gov/116/plaws/publ130/PLAW-116publ130.pdf). The FCC has issued three Orders and Further Notice of Proposed Rulemakings (FNPRM) regarding data mapping and collection. FCC Report and Order for Digital Opportunity Data Collection, WC Docket 19-195, WC Docket 11-10, August 6, 2019 (FCC-19-79A1); Second: July 17, 2020, FCC-20-94A1, and Third: January 19, 2021, FCC-21-20A1). FCC Second Report and Order for Digital Opportunity Data Collection, WC Docket 19-195, WC Docket 11-10, July 17, 2020 (FCC-20-94A1), and Third: January 19, 2021, FCC-21-20A1). FCC Third Report and Order for Digital Opportunity Data Collection, WC Docket 19-195, WC Docket 11-10, January 19, 2021 (FCC-21-20A1).

[15] On February 22, 2022, the FCC announced that providers of fixed and mobile broadband service must provide their broadband availability data by September 1, 2022. https://www.fcc.gov/document/fcc-announces-inaugural-broadband-data-collection-filing-dates. It has been publicly reported that the FCC is aiming to release the initial version of the map in November 2022. After that initial map is released, however , the FCC then is required by law to allow interested parties to challenge the accuracy of reported coverage. That process realistically will take at least several months.

[16] For example, certain structures, such as animal confinement facilities, weather monitoring equipment and oil wells, increasingly require broadband connections yet may not be considered a "serviceable location" by the FCC.

Even if the number of locations that need upgrades to receive broadband were known precisely, it remains a difficult task to determine the cost to construct broadband networks throughout the United States. Customer density is often the primary cost driver of providing broadband, but also terrain differences and many other secondary factors can cause construction costs to be dramatically different from one region to another. Some of these secondary factors include:[17]

- Type of soil for buried construction
- Preparation of facilities f(make ready) or aerial construction
- Availability of Rights of Way
- Other existing utilities in construction corridor
- Local (township, county, city, state) requirements for depth and other factors
- Project size and length of construction season
- State/Federal public lands (parks, forests, etc.)
- Environmentally sensitive areas
- Contractor and material availability
- Cost of labor, fuel, and materials

These factors make construction costs in some regions 10 to 20 times more expensive per location than other regions. For example, underground fiber construction may cost less than $20,000 per mile in some areas but be more than $300,000 per mile in other areas. Not only do these factors make estimating construction costs in a given region difficult, but they also change over time. Moreover, the significant price increases experienced over the last couple of years are expected to continue and will likely accelerate.

3. Overview of Past Attempts to Estimate the Cost of Bringing Broadband to All

Several studies have attempted to estimate the cost to deploy broadband throughout the United States, often with wildly different results. The 2017 de Sa paper estimated it would cost roughly $80 billion to deploy fiber to the estimated 22 million locations that lacked access to 25/3 Mbps-capable cable or FTTP networks. The 2018 BCG study estimated the cost of deploying fiber nationwide to be between $45

[17] In the Matter of a National Broadband Plan for Our Future, GN Docket No. 09-51, Cheryl L. Parrino, November 4, 2010 (https://ecfsapi.fcc.gov/file/7020919782.pdf)

billion and $65 billion. In 2019, Cartesian concluded it would cost $70 billion to pass 90% of all homes with fiber. Then, in 2021, Cartesian updated its analysis to estimate that it would cost between $35 billion and $67 billion to extend fiber to all locations in the country that lack 100/20 Mbps. Finally, Tufts estimated that it would cost $240 billion to extend networks to "close the digital divide." Each of the studies is subject to limitations that cast doubt on their bottom-line estimates. In our analysis, we will primarily focus on the 2021 Cartesian and Tufts studies, while describing some of the limitations of the earlier studies.

3.1. Assumed Technology

The investment needed to provide broadband to unserved and underserved locations is dependent on the technology used. The studies generally estimated the cost to extend a fiber-based broadband network to locations that currently lack 25/3 Mbps service (considered "unserved" in the IIJA). The 2021 Cartesian study also estimated the cost to upgrade locations that lack 100/20 Mbps service (considered "underserved" in the IIJA). Coaxial cable ("DOCSIS"), FTTP, and some fixed wireless solutions can all provide 100/20 Mbps, but we will focus this analysis on those studies that estimate the cost of using fiber to deploy broadband to these locations. When building a new network, a FTTP solution is generally chosen because it normally has lower construction costs compared to copper-based technologies, has lower long-term operational costs, and is more scalable.[18] While the initial capital expense of fiber deployment is expensive, in VPS's opinion, there is no scalable technology being developed that will dramatically reduce the cost of deploying high-speed broadband networks capable of serving the millions of locations that are unserved today. New wireless technologies using better modulation techniques and new spectrum (CBRS, 6 GHz, and mmW) are either limited to line of sight or can only provide broadband over short distances, and the spectrum is often shared with other providers and users. Wireless technologies will have difficulty proving higher speeds in rural areas as user demand continues to rapidly increase. Deploying broadband using a technology that will not easily scale as demand increases will result in the need for significant future investments. Over the long term, it is

[18] A recent study by Andrew Afflerbach, Ph.D., P.E., CTC Technology & Energy, titled, "Fixed Wireless Technologies and their Suitability for Broadband Delivery" ("CTC Study"), June 2022, concluded, "While the cost analysis illustrates that fiber's upfront capital costs are higher than those of fixed wireless in many circumstances, the total cost of ownership over 30 years is comparable for fiber and fixed wireless.", pg. 3.

much more cost effective to build a scalable network the first time rather than incrementally upgrading it as users' demand increases.[19]

3.2. Estimating the Number of Unserved Locations

Each of the studies begin by estimating the number of households (or locations or "Americans") that are unserved. Most of the studies assumed a location was "served" if it had access to a broadband at a speed of 25/3 Mbps or faster – the FCC's definition of broadband service set in 2015.[20] The Cartesian,[21] BCG, and de Sa studies all use Form 477 data to estimate the number of unserved locations. Because the Form 477 reports broadband availability at a census block level, an entire census block is assumed to be served when any single location within the census block is served; however, the estimates relying on such data underestimate the number of unserved locations. As stated by Tufts, "Our state of understanding on access to broadband nationwide is muddled due to inaccurate, outdated data."[22]

Recognizing that estimates based only on Form 477 data were inaccurate, both Tufts and Cartesian relied on a combination of Form 477 data and information from BroadbandNow[23] to estimate the number of unserved locations. The 2021 BroadbandNow study drew a sample of addresses from the 11 largest Internet Service Providers ("ISPs") in the country and used their "check availability" tools to determine the number of locations where service is not available. In the roughly one-third of the addresses examined, where another local ISP's service territory overlapped the service territory of the large ISP according to FCC Form 477 data, BroadbandNow assumed that the other ISP was in fact serving the location. This questionable assumption by BroadbandNow creates yet another area of possible underestimation because the study assumed all the overlapping locations could receive the reported level of service. Even so, BroadbandNow concluded that at least 42 million Americans do not have access

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[19] Future Proof: Economics of Rural Broadband, Comparing Terrestrial Technologies & Investment Considerations to Meet Increasing Consumer Broadband Demands, Larry Thompson, PE, Brian Enga, PE, and Brian Bell, PE, of Vantage Point Solutions for the Foundation for Rural Service, May 2021.

[20] FCC Finds U.S. Broadband Deployment Not Keeping Pace, DA/FCC #: FCC-15-10, January 29, 2015 (https://www.fcc.gov/document/fcc-finds-us-broadband-deployment-not-keeping-pace)

[21] When referring to the "Cartesian study" we are referring to their 2021 study unless otherwise stated, because this study largely replaced their 2019 study.

[22] Tufts Study, pg. 3.

[23] FCC Reports Broadband Unavailable to 21.3 million Americans, BroadbandNow Study Indicates 42 million Do Not Have Access, February 3, 2020, (https://broadbandnow.com/research/fcc-underestimates-unserved-by-50-percent).

to broadband speeds of 25/3 Mbps. Using 2.51 people per household,[24] the number of unserved locations estimated by BroadbandNow is 16.7 million, which is 15% more than the 14.5 million estimated by the FCC in its most recent report to Congress on broadband availability.[25] Recently, CostQuest who is currently developing the broadband maps for the FCC estimated that there is 23 to 25 million homes and businesses that are unserved or underserved by broadband.[26]

The Cartesian study optimistically assumed that all the locations provisionally awarded as part of the RDOF auction would receive service.[27] Since the release of the Cartesian study, the FCC has found some winning bids provisionally awarded in the RDOF auction to be in default.[28] As of July 14, 2022, the FCC had acted on 426 of the 479 long form applications, authorizing a total of $5.2 billion of winning bids to serve nearly 3 million locations, and has announced an additional 11 applications were ready to authorize. However, the applications of several of the largest winning bidders – that collectively represent more than 1 million locations – remain pending. Therefore, it is unclear how many locations with winning bids ultimately will receive support and become served under that program. In any case, given the defaults that have already occurred, it is obvious that not all the 5.2 million customer locations in the areas with winning bids will receive broadband through RDOF. Given this situation, it is reasonable to assume that Cartesian's estimate of unserved locations is too low.

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[24] Statista, Average Number of People per Household in the United States from 1960 to 2021, (https://www.statista.com/statistics/183648/average-size-of-households-in-the-us/) based on US Census data.

[25] FCC's Fourteenth Broadband Deployment Report, In the Matter of Inquiry Concerning Deployment of Advanced Telecommunications Capability to All Americans in a Reasonably Timely Fashion, GN Docket 20-269, January 19, 2021, ¶ 2.

[26] LightReading, "CostQuest counts 23-25M homes, businesses unserved or underserved by broadband", June 16, 2022.

[27] Using the June 2020 Form 477 data, Cartesian determined there were 8.2 million locations in the fully unserved census blocks that could not get 25/3 Mbps broadband and then deducted 5.2 million locations provisionally awarded as part of the RDOF auction. To account for the unserved locations in the partially served census blocks, Cartesian utilized a 2020 study conducted by BroadbandNow that estimated there were an additional 8.2 million locations lacking 25/3 Mbps that are not accounted for in the Form 477 data.

[28] Winning bidders have defaulted due to failure to complete long-form application requirements, including failing to obtain state ETC designation and failing to apply for state ETC designation in a timely fashion. While the FCC has released a list of census blocks for which there has been an announced default, that list does not provide the associated number of locations for each such census block, making it difficult to determine the total number of locations already subject to default.

To improve on the data provided by Form 477, the Georgia Broadband Program ("GBP") attempted to determine the broadband availability at every location in Georgia.[29] VPS acquired the GBP dataset and compared it to Form 477 data[30] of the same period to determine by how much the Form 477 process understates unserved locations in Georgia. The Form 477 process identifies a census block as being served if *any* location in the census block is served and identifies the census block as unserved only if *all* locations in the census block are unserved. Using the Form 477 method, 141,012 locations are estimated to be unserved in Georgia. In contrast, the actual number of unserved locations according to GBP study is 449,210, as shown in Table 3-1. Thus, the GBP Study shows that the number of unserved locations using Form 477 is understated by a factor of 3.2. This result correlates closely with the Cartesian study, which showed that the Form 477 understated unserved locations by a factor of 3.16.[31]

Study	Form 477	Georgia Broadband Program
Served Locations	5,178,927	4,870,729
Unserved Locations	141,012	449,210

Table 3-1: Summary of Form 477 and GBP Comparison

As described above, there is little agreement on the number of unserved locations among those that have estimated the cost of broadband nationwide. Even using a consistent definition of broadband, 25/3 Mbps, the estimate of unserved locations in the four studies ranges from 8 million to 22.4 million[32] – varying by a factor of 2.8 times.

3.3. Estimating the Number of Underserved Locations

As the minimum broadband speed standard increases, the number of locations needing broadband upgrades increase as does the cost of the broadband upgrades. The cost estimates in most studies fail

[29] FCC vs Georgia Broadband Program Comparison, Georgia.gov, Georgia Broadband Program, 2022 (https://broadband.georgia.gov/fcc-vs-georgia-broadband-program-comparison). For purposes of the GBP study, broadband was defined as the ability to receive 25/3 Mbps.

[30] Using June 2020 FCC Form 477 data, which is the same timeframe used by the Georgia Study.

[31] The Cartesian study estimated there were 3.8 million locations that could not get 25/3 Mbps when considering the fully served census blocks in the FCC 477 forms and 12 million locations if the partially served locations are included (page 5).

[32] BCG study estimated 20 million people were unserved (BCG study, page 1) with equates to approximately 8 million locations and de Sa believed there to be 22.4 million unserved locations (de Sa study, page 2).

to address the cost of reaching locations that Congress has now defined as underserved.[33] While the 2021 Cartesian study estimated the number of locations lacking broadband at different speeds, other studies only estimated unserved locations using the FCC's broadband definition of 25/3 Mbps. Specifically, the Cartesian study estimated that there were 10.6 million underserved locations that could not get 100/20 Mbps, and 3.8 million unserved locations that could not get 25/3 Mbps. Thus, according to the Cartesian study, there are 2.8 times more locations that cannot get 100/20 Mbps compared to the number of locations that cannot get 25/3 Mbps.[34] VPS performed a similar calculation by analyzing fully served census blocks using Form 477 data from June 2020 and found that there were 2.5 times more housing units in fully underserved census blocks where no location could receive 100/20 Mbps than housing units in census blocks where no location could receive 25/3 Mbps.[35] VPS multiplied this ratio, 2.5, by the approximately 18 million locations[36] in both totally unserved and partially unserved census blocks that cannot receive 25/3 Mbps to estimate the total number of locations lacking 100/20 Mbps. This results in approximately 45.5 million locations lacking 100/20 Mbps in the United States as of June 2020.

3.4. Estimating the Cost per Location

In addition to estimating the number of unserved and underserved locations in the United States, one must also estimate the average investment required per location to determine the investment required to construct fiber broadband networks to all. Using 25/3 Mbps as the baseline speed, we can calculate the average investment cost used in each study by dividing the total study's cost by their estimated unserved locations, as shown in Table 3-2.

[33] Congress in the IIJA defined locations with less than 100/20 Mbps as underserved. IIJA, Section 60102 (a) (C).
[34] Cartesian study, page 5.
[35] Form 477 includes fully unserved census blocks and served census blocks, which could be fully served or partially served. VPS found that 5,681,521 housing units were in census blocks where no location could receive 25/3 Mbps, and 14,256,417 housing units were in census blocks where no location could receive 100/20 Mbps. The ratio of these housing unit counts is 2.5. The VPS calculated factor of 2.5 is reasonably comparable to the Cartesian factor of 2.8.
[36] To estimate the 18 million locations lacking 25/3 Mbps broadband, VPS multiplied the 5,681,521 housing units in census blocks where no location could receive 25/3 Mbps by 3.2 from the GBP study to adjust the Form 477 data to include the unserved locations that are within a partially served census block.

Study	Study Year	Cost per Unserved Location
de Sa	2017	$3,571
BCG	2018	$2,250 - $3,250
Cartesian	2021	$1,818 - $3,364
Tufts	2021	$5,714

Table 3-2: Investment per Unserved Location at 25/3 Mbps

There is little agreement in the per-unit investment cost among the studies. The disparity in investment cost per location could be because the studies were conducted at different times or because the studies used different sources for the per-unit deployment costs. In any case, the methodologies used in each of the studies resulted in unit costs that are too low, as described below:

- The de Sa study was based on the FCC's Connect America Cost Model, which was originally developed in 2009 for the National Broadband Plan, and then subsequently modified and finalized over a two-year time frame between 2012 to 2014. The underlying inputs in the model – both for capital investment and operating expenses – have not been materially changed for more than a decade. In fact, the inputs were derived from telecommunications industry data reported between 2007 and 2010 – a full 12 to 15 years ago. The investment required to deploy broadband has increased significantly over the last few years due to increasing costs, such as labor and material, as well as costs associated with factors such as environmental and supply chain issues.
- The Cartesian study estimated the cost to extend fiber to unserved and underserved locations based on two sets of flawed data. The low-end estimate, $1,818 per location, was derived from winning bids in the RDOF Phase I auction gigabit service tier, differentiated by household density. All winning bids, including gigabit bids for firms planning to use fixed wireless or hybrid network technologies, as well as bids of firms that have subsequently defaulted, were included. The estimate was based only on the amount of RDOF support, without considering end-user revenues or other revenue sources, such as state grants, that the winning bidders may have relied upon to fund the construction when determining what bids to place. The high-end estimate, $3,364 per location, was based on fiber deployment projects serving areas with a density of *1,000 or more* homes per mile.[37] Clearly, these fiber projects are not representative of low-density rural markets where most unserved and underserved locations are located.
- BCG's FTTH cost estimates, between $2,250 and $3,250 per location, were based on its August 2014 study on the cost of deploying broadband in rural Australia. BCG states, "We

[37] These projects include Google Fiber in Kansas City, and a Tennessee municipal fiber build (assumed to be Chattanooga), as well as projects by Verizon Fios and Cincinnati Bell.

> adjusted those costs for US county populations, coverage, and density, correcting for inflation, currency conversion, and differences in labor costs. We compared the fiber-to-the-home costs with the costs of fiber rollouts in other parts of the US and in Europe to validate their continued applicability."[38] BCG did not provide sufficient information, however, to assess the validity of its methodology.

The investment per unserved location assumed by the various studies is typical of what one might expect if estimating an average for *all* broadband customers in the United States and are not reflective of the significantly higher cost of installing fiber in less densely populated, rural areas. The locations lacking adequate access to broadband are predominantly in areas where there is no business case to build a broadband network when relying upon end user revenues alone. If the investment cost were as inexpensive as some of the studies suggest (less than $2,000 per location), it is likely that no government support would be needed at all because end user revenues would cover the cost over a reasonable time horizon. When estimating the cost of deploying broadband nationwide, the investment cost per location should be representative of those locations that lack broadband today. In the United States, the unserved and underserved customers are predominantly in the low density, rural areas, which have the highest investment cost per location.

3.5. Total Investment Needed to Provide Broadband to the Unserved

Total investment estimates vary widely among the studies, as shown in Figure 3-1. The investment amounts depicted in Figure 3-1 represent the estimated amount necessary to construct fiber facilities to offer broadband service only to those locations that cannot receive 25/3 Mbps. However, there are many locations in the United States that can receive 25/3 Mbps or higher speeds but lack the speed that Congress has now determined to be "underserved," which is 100/20 Mbps. Cartesian estimates that by changing the broadband definition from 25/3 Mbps to 100/20 Mbps increases the number of locations requiring upgrades by more than 70%.

[38] BCG Study, page 2.

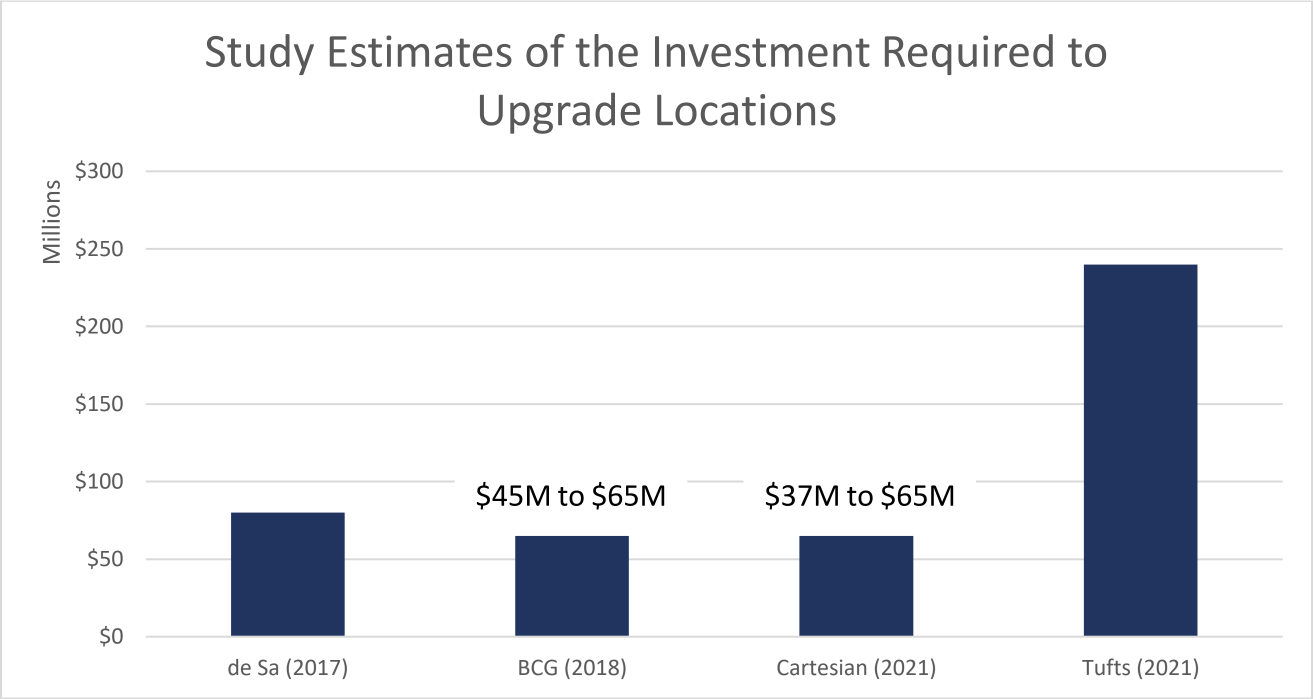

Figure 3-1. Estimated Investment Required for Broadband for All

As described previously, VPS also analyzed Form 477 and census data to estimate the number of locations lacking broadband at both a 25/3 Mbps standard and a 100/20 Mbps standard. VPS found that by changing the broadband definition from 25/3 Mbps to 100/20 Mbps would result in 2.5 times more locations and therefore require significantly more investment.

4. VPS's Perspective Based on Real World Engineering Analysis

Each of the studies discussed in this paper estimated the number of locations that lack broadband and then attempted to determine the cost for upgrading these locations to receive broadband at some speed threshold. While there was little agreement on the number of unserved locations in the studies, the FCC's Digital Opportunity Data Collection effort, once the mandated challenge process is completed, should help resolve this issue.[39] Based on the previous analysis using June 2020 Form 477 data, approximately 45.5 million locations would require upgrades to meet the 100/20 Mbps standard set by Congress. An even bigger challenge than estimating the number of locations to be upgraded, however, is to determine the investment required, on average, to upgrade these locations using FTTP, which is the only scalable broadband technology that will "meet the evolving connectivity needs of homes and businesses."

Most of the cost when installing fiber is in the mainline cable infrastructure, either buried or aerial, not in the electronics. As more customers can share the cost of the mainline cable and other common network components, the cost per location decreases. Assuming other factors such as terrain being similar, the cost per location to deploy broadband is highly dependent upon the density of the area being served—low density areas are generally the highest cost. In low population areas, the mainline costs are often much higher than the drop costs on a per-location basis. The customer connection or "drop" consists of electronics at the customer premises and a fiber cable that connects the customer premises to the mainline fiber – typically, the length of the driveway from the house to the road. With material and installation, FTTP electronics cost between $700 and $1,000 per location,[40] and rural fiber drops, (which in many areas can exceed 300 feet due to longer driveways to the home on farms or ranches) cost between $1,500 and $2,000. Thus, the cost to connect a rural location can be between $2,200 and $3,000 ***before*** including costs associated shared facilities.[41] In the de Sa, BCG, and Cartesian studies, the estimated cost per location was barely high enough to cover the cost of the drop without considering costs associated with the mainline fiber construction.[42]

The cost for mainline construction varies significantly across the United States depending on the type of soil, access to poles, the existence of other utilities, availability of contractors, and environmental considerations. Generally, rural mainline construction costs at least $20,000 per mile (including all labor, materials, permitting and engineering), but can be substantially higher. Using actual construction data

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[39] In the Matter of Establishing the Digital Opportunity Data Collection and Modernizing the FCC Form 477 Data Program, WC Docket No. 19-195 and 11-10.
[40] The electronics cost includes electronic equipment at the customer premises and a share of the central office electronics.
[41] The cost of shared facilities includes the allocated cost of the mainline fiber, as well as a share of shared equipment such as routers.
[42] See Table 3-2.

from each region, VPS determined average cost for mainline construction to be approximately $48,000 per mile for the rural areas engineered for the RDOF auction. Figure 4-1 shows the estimated cost per location for various customer densities when assuming $20,000, $40,000, and $60,000 per mile for mainline construction.[43] This chart is not intending to imply that all rural construction is between $20,000 and $60,000 per mile, because there are many areas where construction is significantly more than $60,000 per mile, but rather to show the sensitivity to the cost per location as the customer density and mainline construction costs are varied. Depending on the cost of mainline construction, Figure 4-1 shows that the cost per location can vary from $7,000 to $15,000 when the customer density is five locations per mile and about double that when the customer density is two locations per mile.

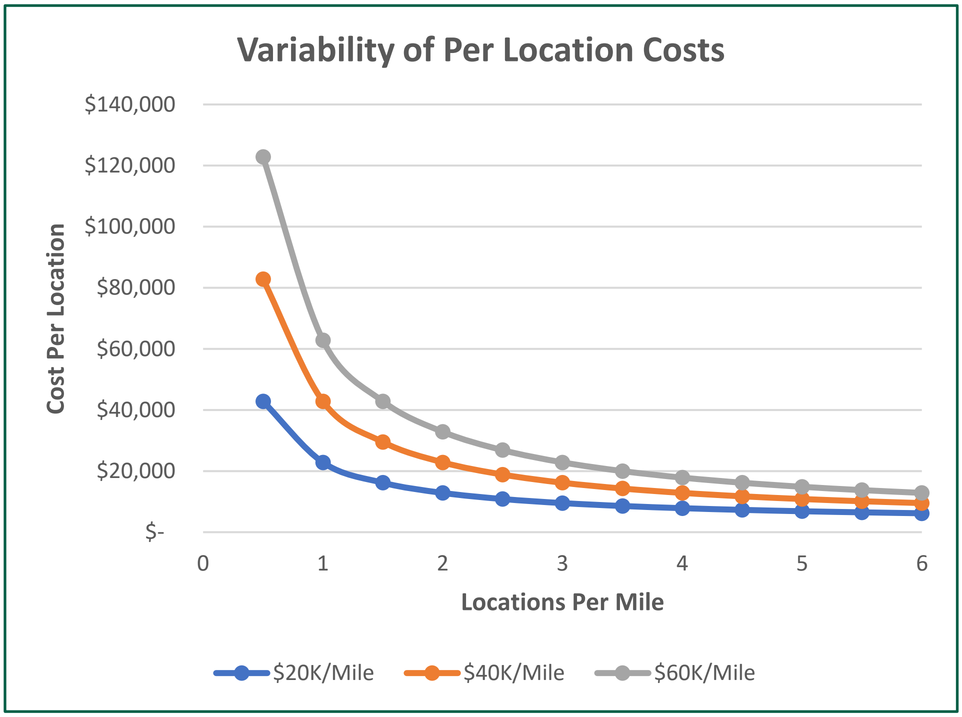

Figure 4-1. Relative Per Location Costs

Because areas remaining unserved are likely extremely rural, those locations that lack broadband across the United States are likely similar in cost characteristics to unserved locations included in the RDOF auction.[44] In preparation for the RDOF auction, VPS performed over 50 preliminary FTTP

[43] It should not be assumed that $60,000 per mile is the highest cost. VPS has seen some areas where the cost per mile is more than $300,000.

[44] In many instances, VPS was creating engineering designs for the higher density RDOF eligible areas, where it was easier to make a business case at or near the RDOF reserve price.

engineering designs for companies across the United States.[45] These designs provided fiber connectivity to all locations within the eligible census blocks. In this analysis, a sampling of VPS's average engineering cost per location for RDOF will be used to determine an appropriate average cost per unserved location.

When the cost per location used in any of the studies (de Sa, BCG, Cartesian and Tufts) is compared to VPS's actual engineering designs, the assumed cost per location is only about 25% to 50% of the actual engineered cost.[46] An average mainline cost of $48,000 per mile and a linear density of 5.8 locations per mile would yield an approximate average cost of $11,000 per location based on VPS's RDOF engineering designs,[47] but based on our experience, this engineered cost is likely lower than the per location cost of the remaining unserved locations in the United States. First, the areas engineered by VPS were more densely populated than the average RDOF area,[48] and the cost per location increases dramatically as the density decreases. Second, when considering a multi-year investment, construction cost increases must also be considered. The RDOF engineering analysis was performed nearly three years ago (prior to the pandemic), and costs now are higher. Moreover, construction to upgrade all unserved locations will likely take several years to complete, so future cost increases must also be considered. To determine the effect of construction cost increases over recent years, VPS analyzed numerous contracts in a specific geographic region.[49] The trend line, shown in Figure 4-2, represents an increase of about 8% per year on average from 2017 to 2021. Indications are that upward pressures on construction costs will continue for several years due to labor and material shortages. In fact, it is not uncommon to see construction cost in 2022 that are 25% higher than 2021.

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[45] These networks were in Alabama, Georgia, Iowa, Illinois, Indiana, Kentucky, Michigan, Missouri, Montana, North Carolina, North Dakota, Oklahoma, Pennsylvania, South Dakota, Texas, and West Virginia.

[46] See Table 3-2.

[47] A illustrative example in a study conducted several years ago by CostQuest Associates ("CostQuest") provided results consistent with VPS's estimate. Assuming mainline construction to be around $35,000 per mile, CostQuest calculated the cost per location for two and eight customers per mile to be $17,415 and $4,597, respectively. Rural Broadband Economics: A Review of Rural Subsidies, Steve G. Parsons and James Stegeman, CostQuest Associates, 2018, pp. 12-13.

[48] The average density for all these designs was 5.8 locations per mile.

[49] Costs from only one geographic region was analyzed to eliminate construction cost differences due to differing soil types and other factors.

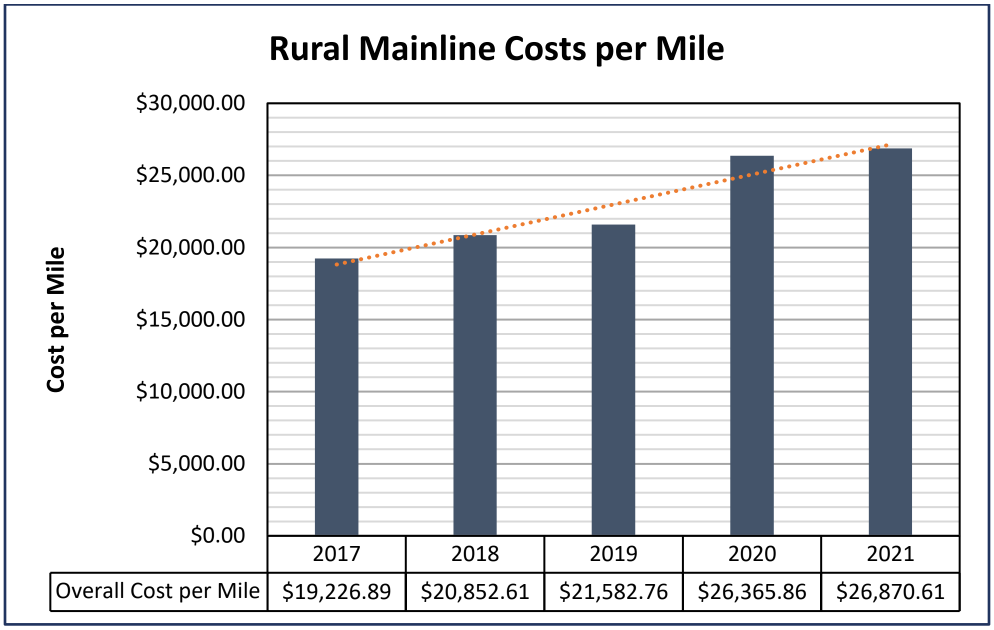

Figure 4-2: Example of Average per-mile Rural Construction Costs

To estimate the cost of FTTP construction nationwide, VPS estimated the cost of upgrading unserved locations and underserved locations separately. While VPS's RDOF engineering designs for locations not capable of 25/3 Mbps averaged approximately $11,000 per location, this estimate is nearly three years old. If we were to apply the average inflation rate of 8% from Figure 4-2, the per-location construction cost estimate now would be $15,000. The cost per location to upgrade underserved areas already capable of 25/3 Mbps but not capable of 100/20 Mbps will be lower than the cost to upgrade unserved locations for two reasons: (1) the areas are probably more density populated so the construction cost is lower and (2) to achieve these higher speeds, the provider has likely already replaced some copper cable plant with fiber. For these reasons, we assume that the cost to extend the fiber network to the underserved locations to be in a range of $6,000 to $9,000 per location.[50] Assuming only 70% of the locations subscribe (and therefore require a drop to the house), the cost to make service available to the 18.1 million unserved locations is estimated to be $256 billion and the cost to make

[50] The CTC Study estimated that the cost of passing for low-density and very low-density areas are between $6,240 and $42,370 per location. As discussed previously, the cost to connect a location would increase these costs by $2,200 to $3,000 per location.

service available to the 27.3 million underserved locations is $141 billion to $222 billion, making the total cost $397 billion to $478 billion.

A few considerations could influence our cost estimate.[51] The calculations were based on FCC 477 data that is already two years old. A considerable number of broadband locations have already been built using state and federal funds, which will decrease our cost estimate. Nevertheless, even if our estimate of the unserved locations is off by a factor of two, the cost to upgrade would still be $200 to almost $250 billion, which is still much higher than the funding provided for in the IIJA. Fewer potential locations to deploy is in part offset by cost increases. Inflation has been significantly higher in 2022 than the average inflation rate derived from 2017 to 2021 data, and we expect higher inflation to continue as the demand for more broadband construction results in supply chain issues and labor shortages. Further, the BEAD funding comes with prevailing wage requirements, environmental requirements, and other reporting requirements that could also increase the costs over what was estimated for RDOF. On balance, we believe that our cost estimate remains reasonable. In VPS' opinion, the cost could likely exceed $400 billion

Regardless, the price tag to provide broadband to all is significantly more than the funding Congress has appropriated for broadband deployment in the IIJA and other measures recently signed into law. The funds allocated in the IIJA will help bring broadband to millions of locations that would otherwise be on the wrong side of the digital divide, but even when considering providers' matching funds, in VPS's opinion, the funds appropriated will fall woefully short of the amount necessary to connect all Americans to a fiber broadband network. Plus, even fiber networks do not run themselves and do not last forever, so additional investment will be required to maintain and upgrade these networks. The cost to bring broadband to all is high, but the cost of failing to do so is higher.

[51] Some less scalable technologies could likely be used to achieve the 100/20 Mbps standard in the IIJA. While doing so may reduce the initial capital expenditure; additional investments would be needed in the near-term to keep pace with rapidly increasing customer demand.

About the Authors

Larry Thompson, PE

Larry is the CEO of Vantage Point Solutions, a national provider of engineering and consulting services to broadband providers. He is a licensed professional engineer and has been designing satellite, wireless, and wireline broadband networks for more than 30 years.

Prior to founding Vantage Point Solutions in 2002, Larry held several engineering and management positions with TRW's Space and Defense Sector, CyberLink Corporation, and Martin Group. Over the years he has helped his clients successfully manage many technical, regulatory, and financial challenges when deploying wireless and wireline networks.

He is a two-term member of the FCC's Broadband Deployment Advisory Committee (BDAC), and a frequent speaker at state and national conferences. Additionally, he frequently serves as an expert witness at utility commission and legal proceedings relating to telecommunication technology and regulatory matters.

Larry received his bachelor's degree in Physics from William Jewell College and bachelor's and master's degrees in Electrical Engineering from the University of Kansas.

Cole Donahue

Cole Donahue brings five years of industry experience to the Vantage Point Engineering team, where he adds exceptional cost research and management insight to both aerial and buried fiber deployments.

He is invaluable on grant and loan applications, having supported multiple successful applications for state and federal funding programs. Cole adds additional strength in project management as well – especially navigating the complexity of simultaneous, asynchronous construction timelines. Additionally, he is often involved in electronics selection and strategy.

Cole holds a bachelor's degree in electrical engineering from South Dakota State University.

Vantage Point Solutions Overview

Combining professional engineering, technical expertise and extensive regulatory knowledge, Vantage Point Solutions (VPS) designs technically advanced and economically viable solutions for sustainable, reliable, future-proofed connectivity. VPS provides a full range of services from financial and regulatory consulting to engineering and cybersecurity to outside plant field collection, mapping, and plant documentation.

VPS's Outside Plant professionals oversee more than 10,000 miles of fiber construction each year, providing project management solutions for every phase of construction: from initial design and field engineering, to bid management, permitting, environmental reviews, inspection, documentation, and close-out.

VPS's funding team has secured more than $2.5 Billion in grant, auction, and loan funds for broadband providers. We have been successful with state grants, federal grants, FCC auctions, traditional lenders, RUS, ReConnect, Community Connect, regional and specialty programs, BIP stimulus, NTIA stimulus, and others. These programs, while diverse, nonetheless nearly all require two common components: engineering plans and financial projections. VPS offers both services under the same roof, and that synergy has been key to client success in securing billions for their networks.

Progressive thinking, professional experience, ethical business practices and a legacy of advocacy have established VPS as an industry leader. VPS serves clients in 46 states coast-to-coast. Our boots-on-the-ground staff work side-by-side with client personnel, allowing our services to be continually informed with fresh-from-the-field insights. This broad perspective is invaluable for the 700+ clients we serve.

As industry leaders and thought leaders, the senior leadership at VPS are so much more than management. Company leaders are hands-on, working directly with clients and staff to find solutions for some of the most pressing challenges and opportunities facing an ever-changing industry.

With licensed professional engineers and regulatory experts under the same roof, we are able to understand the big picture for any company. We offer a level of experience and expertise that will give peace of mind throughout an entire project. Team members make smart decisions in the most timely, cost-effective manner possible. We offer a level of customer service that goes above and beyond expectations.