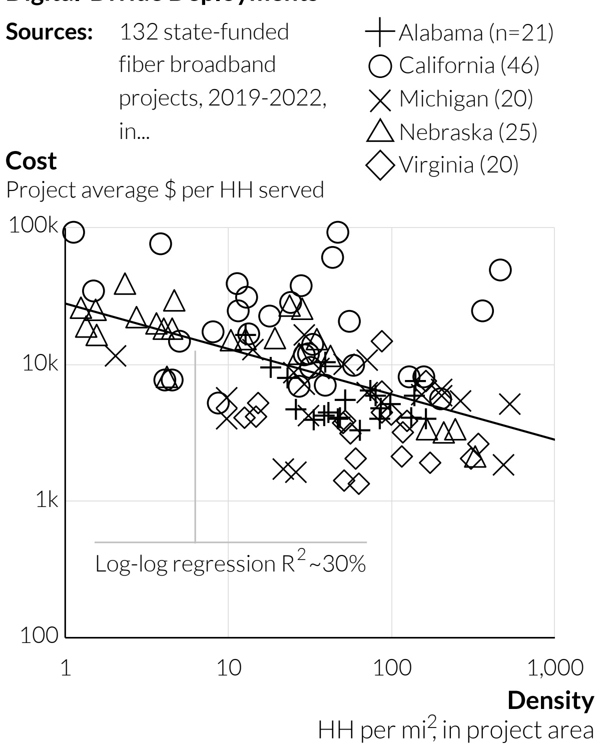
NETWORK ECONOMICS

COST OF 100% FIBER IN CLOSING THE US DIGITAL DIVIDE WILL EXCEED FUNDS AVAILABLE BY ~5X

While broadband service over fiber is ideal, it's important to acknowledge there are situations where it is neither practical nor reasonable, due to high deployment costs and unacceptably long timelines to service. This is most clear in government-funded divide projects, where circumstances inherently make normal commercial business-case metrics unsound. Understanding clearly the costs of fiber and other technologies is critical for policymakers, to ensure that policy objectives can be met with available funds. Unfortunately, gaining that understanding is challenging, given wide variations in fiber deployment methods, local circumstances, and hence real-world costs.

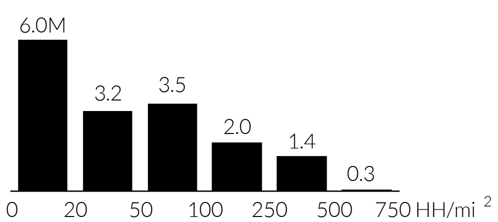
The Tarana team has recently worked to solve this problem by tapping detailed public-domain data[1] from 132 divide projects funded by state-level broadband offices since early 2019, in a set of 5 states (Alabama, California, Michigan, Nebraska, and Virginia) chosen specifically to represent fully the wide range of fiber deployment conditions and challenges across the US. The deployments examined were designed to serve a total of 52.7k homes at an aggregate cost of $733.5M (on average a taxpayer-shocking $13.9k per household served). We used this data to model the likely cost of fulfilling the intent of the broadband element of the US Congress' 2021 Bipartisan Infrastructure Law, with its stated goal of reaching 100% of America's households with fast, affordable internet service. As shown below, extrapolation from the projects sample indicates that **a fiber-only approach would cost over $200B to serve the 16M families currently identified as un- or underserved by the FCC**[2][3]. Obviously this far exceeds the $42.45B available in the Broadband Equity, Access, and Deployment program (BEAD) that is the broadband component of the Bipartisan Infrastructure Law. **This finding *clearly* indicates the need for additional technology approaches to the problem** — and naturally Tarana recommends our unique next-generation fixed wireless platform (ngFWA), which has now been well-proven to deliver fiber-class broadband performance at a fraction of the cost and deployment time, wherever fiber economics are challenging. Altogether, fiber, ngFWA, and LEO satellite constellations for very remote locations comprise a comprehensive and practical toolkit for closing the increasingly important yet persistent digital divide at reasonable costs. The graphs below summarize the analysis — a detailed walk-through of their development follows.

Fiber Costs Profile in Digital-Divide Deployments



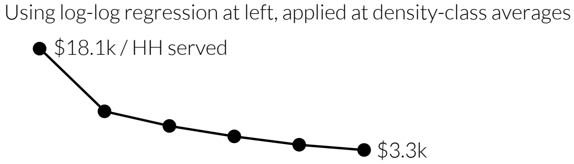
Distribution of ~16M Un-/Underserved US HH

Estimate based on HH density pattern in divide projects sample



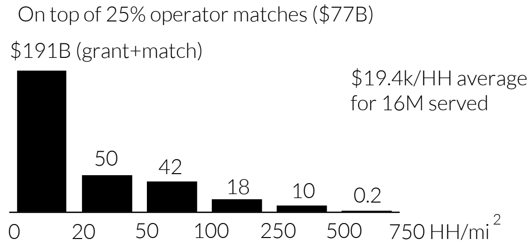
Cost = f(Density) Model from Fiber-Project Actuals

Using log-log regression at left, applied at density-class averages



~$230B BEAD Funds Required for 100% Fiber

On top of 25% operator matches ($77B)

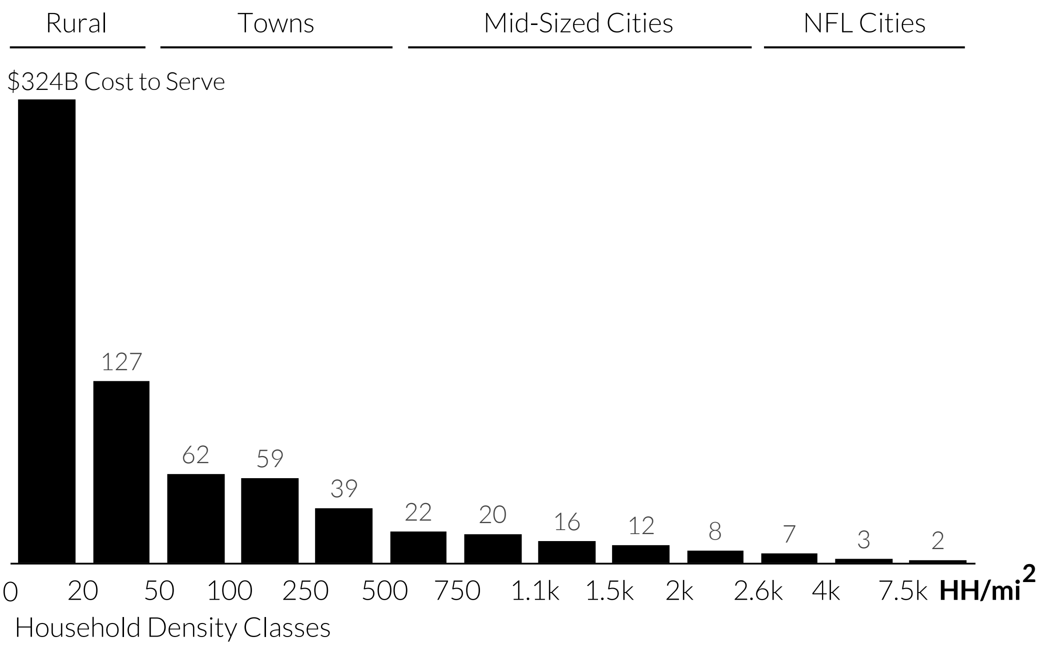


Sources: US state broadband offices in AL, CA, MI, NE, & VA. FCC Broadband Map. US Census & Labor Bureaus. Tarana statistical analysis.

We also used the sample-driven cost model (independent from addressing BEAD objectives) to estimate the cost of fulfilling the grander aspiration held by many in the fiber equipment business, and in telecoms generally (both public and private sector) — namely to reach every household in the US with fiber. With some sensible approximations of current fiber penetration by household density class added to the project data set (which are explained in the next section on the mechanics of these analyses), it was straightforward to arrive at the conclusion that this aspiration is unlikely to be met soon, given the high costs in the lower-density classes. See below.

$B to Go $\sum \cong$ **$700B**

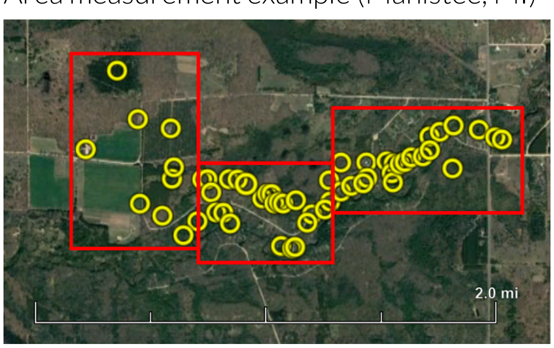
Estimated cost of serving the remaining ~56M US HH with fiber, by HH density class, extrapolating from 132 state divide-project actuals



Analysis Approach:

Tarana's compilation of and extrapolation from the 132 divide projects sample was conducted as follows:

Area measurement example (Manistee, MI)

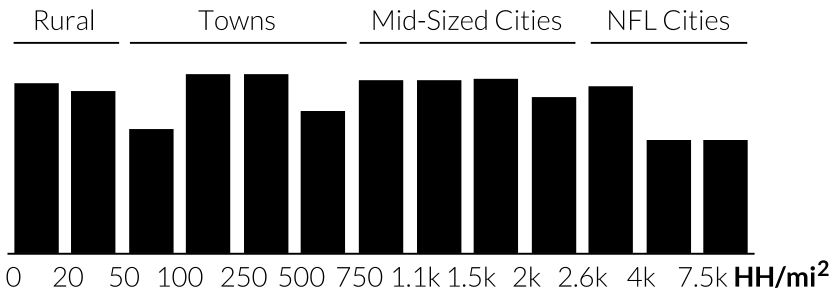


Step 1: Three key metrics — total cost (grant + match), subscriber count, and geographic area covered — were collected from each fiber project's documents. For most, area in mi^2 needed to be derived by digitally scaling diagrams or KML plots and measuring polygons or target-HH location sets provided (as shown here).

Separately, given a number of projects in Alabama where labor vs. materials mix was available, their average mix[4] was used to adjust total costs per project across the sample to US average construction wage rates[5], to yield more representative extrapolation to the rest of the US.

Projects included in the sample were chosen at random from Virginia's large pool but otherwise included all new-build projects from each state.[6]

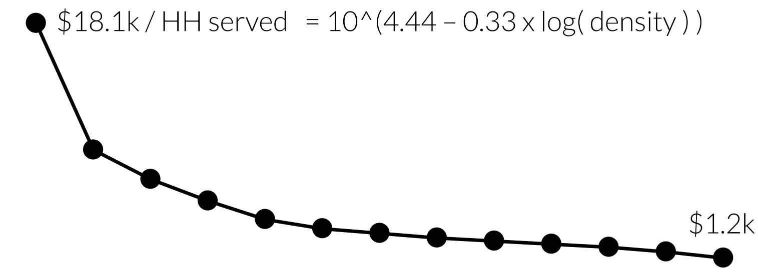
132M US Households — Density Profile (per US Census)



Step 2: A histogram of US household density was constructed from US Census Bureau data at the tract level (77k data points)[7], to enable application of the cost model at a manageable number of discrete density points (the class averages) along the curve in Step 3.

Cost = f(Density) Model Based on Divide-Project Actuals

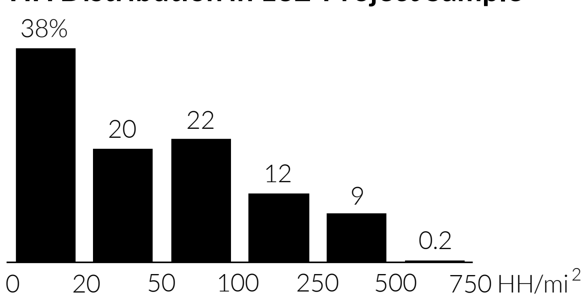
Using log-log regression on 132 AL, CA, MI, NE, and VA fiber projects' metrics, applied at histogram class averages



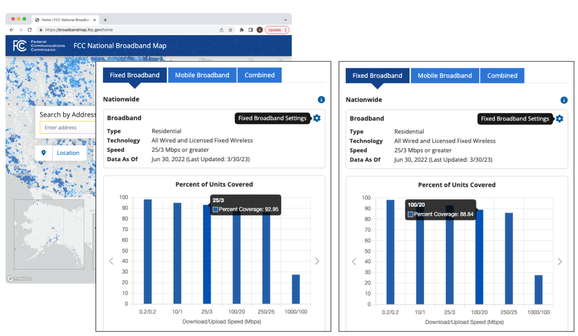
Step 3: A log-log regression on $ per HH served as a function of HH density from the project sample (recall page 1 here) was used to calculate $k per HH served at each density class average point. The regression's R^2 was ~30%.[8]

Step 4: These per-HH estimates by class average were inflated to then-year $ to reflect the US construction industry's recent bout of inflation and forecast return its normal 3% annual rate[9].

HH Distribution in 132-Project Sample



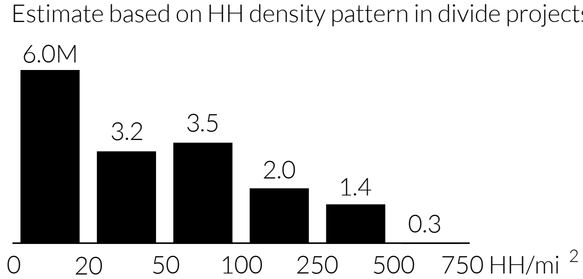
Step 5: A histogram was created to profile the proportion of households in the complete set of 132 projects in a range of household density classes, consistent with those used in Step 2.



Step 6: The FCC's Broadband Map was tapped for a current report on the nationwide penetration of wired plus licensed fixed wireless broadband at the 25/3 speed level (92.95%), yielding 7.05% unserved, and the same tech at 100/20 (88.84%), an incremental 4.11%, underserved, by the NOFO definitions, for a total of 11.1% un-/underserved. Given that challenges to the map continue, this figure was factored up by 10% to reflect a likely but modest increase in the un-/underserved proportion, and then multiplied by 132M households in the US (per the Census Bureau), to yield 16M households in the category.

Distribution of ~16M Un-/Underserved US HH

Estimate based on HH density pattern in divide projects sample



Step 7: To facilitate straightforward development of an estimate of cost to serve the 16M un-/underserved households, the sample projects' HH distribution from Step 5 was used to estimate the likely distribution of the 16M un-/underserved HH from Step 6 — assuming that future divide-closing projects will involve similar degrees of geographic HH distribution as past divide-closing projects, to a first-order approximation.

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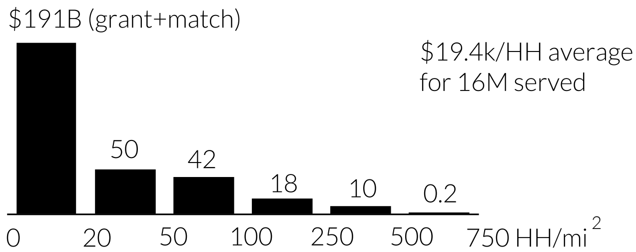
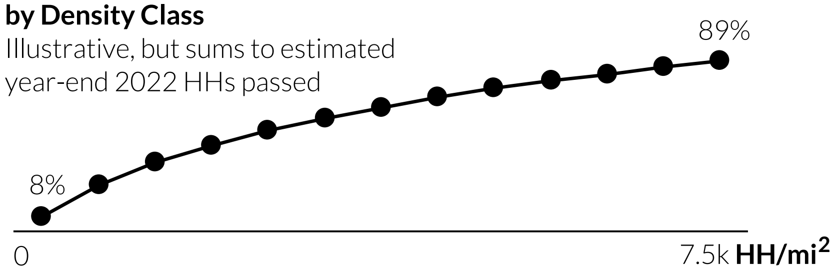


Step 8: The HH distribution from Step 7 was multiplied (density class by class) by the costs in the Step 3/4 model to get total cost per class. Their sum was then multiplied by 0.75 — to remove operators' obligatory 25% match — yielding an estimate of the total cost to the BEAD program of reaching / upgrading the 16M un-/underserved homes with a fiber-only approach.

Estimated Year-End 2022 US Fiber Penetration by Density Class

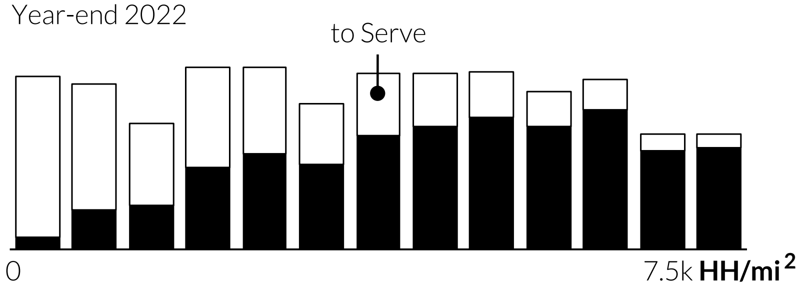
Illustrative, but sums to estimated year-end 2022 HHs passed



Step 9: Separate from the BEAD analysis, to enable estimation of the cost to build out fiber to the 56M US HH not yet passed, current fiber penetration as a function of density class was estimated to reflect the commonly understood exponential increase in fiber costs as density decreases[10], driving a curve in which highest penetration has occurred where the commercial business case for fiber is strongest, lowest where the case is weakest, and with a negative second derivative of penetration with respect to increasing density. Total current penetration was sourced from the Fiber Broadband Association[11].

Estimated Distribution of 55.8M US HH Yet to Serve

Year-end 2022



Step 10: HHs yet to serve was calculated as Step 2's density profile HH count x (1 – Step 9's penetration percentage) for each density class. These values were multiplied (also class by class) with the cost = f(density) model from Steps 3 and 4, yielding the chart at the top of page 2.

Notes:

[1] State-office project sites from which the 132 divide project sample was sourced:
AL: https://adeca.alabama.gov/broadband/
CA: https://www.cpuc.ca.gov/industries-and-topics/internet-and-phone/california-advanced-services-fund
MI: https://www.michigan.gov/dtmb/policies/governance/cmic-grant
NB: https://gis.ne.gov/portal/apps/webappviewer/index.html?id=9dc876af8ea541daa28d7dc82378e5ca
VA: https://www.dhcd.virginia.gov/vati

[2] Physical fiber deployment details vary from one technology variant to another for the distribution part of the network, but generally "passing" means installing fiber along the highway or street to run past a given set of households at the end of their (often long, in these projects) driveways, thereby providing the availability of fiber-based service, potentially. "Serving" means making a "lateral" connection from that distribution fiber into the home and providing service. The projects in our sample were proposed and funded to provide both of these elements.

[3] Derived from capture on 4/12/23 at broadbandmap.fcc.gov of national-level, all wired and licensed fixed wireless residential services ≥25/3 Mbps, at 92.95%, leaving the NTIA definition of "unserved" at 7.05%; and the same for ≥100/20 Mbps, which at 92.95% indicates an additional 4.11% of HH are "underserved". An expected "contested" uplift of 10% on both of those figures, to 7.75 and 4.52 respectively, was applied in subsequent analysis.

[4] Alabama's 22 projects' average labor % of total project costs was 68%.

[5] Relative weekly construction wage factors by state in the sample, for reference, are:

Alabama	0.88
California	1.41
Michigan	0.81
Nebraska	0.97
Virginia	1.15
US (Average)	1.00

(source: US Bureau of Labor Statistics, Q3 2022 data)

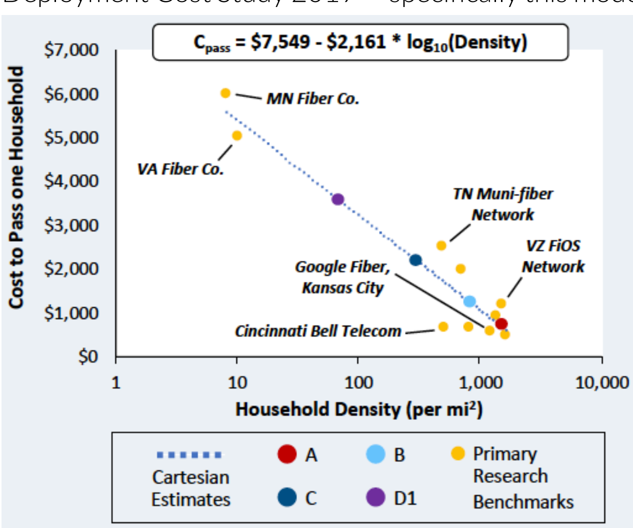
[6] See Appendix for the list of projects and their individual total $, subs count, and area-covered values.

[7] US Census per-tract population data pulled in 2019.

[8] As an aside: regression on x = log (of density) and y = cost/HH (as in the Cartesian model[10]) on the projects sample yielded an R^2 of only 10% and was discarded.

[9] Source for relevant inflation history and forecast (a return to historical averages assumed here as the simplest form of such): US Bureau of Labor Statistics Producer Price Index for non-residential construction, Q1 2012 through Q1 2023.

[10] Evidence: Cartesian consultancy's work published by the Fiber Broadband Association — from their All-Fiber Deployment Cost Study 2019 — specifically this model:



[11] For current US fiber penetration, see: https://www.fiercetelecom.com/broadband/fba-report-43-us-households-now-have-access-fiber, in which Gary Bolton (President of the Fiber Broadband Association) reported that year-end 2020 penetration was 54M and year-end 2021 was expected to be 60M, up 12%. Maintaining that 12% growth rate into 2023 yields 75.9M covered, and 55.8M yet to pass, at year-end 2022.

Appendix — The 132-Project Sample

State	Provider	Project Name	Project Total $k	HH	$/HH	sq.mi.
Alabama	Coosa Valley Tech	Coosa Valley	4,426	746	5,933	10.1
	Covington Electric	Covington	5,549	804	6,902	5.8
	Hayneville Fiber Transport	Ebeneezer Rd.	137	32	4,275	1.2
		Poorhouse Community	257	70	3,676	1.5
		Shirling Lake	368	52	7,075	2.2
	Point Broadband	Macon	3,153	869	3,628	10.3
		Overlook	205	56	3,661	0.3
		Spring Villa	204	38	5,381	0.3
		Waverly	1,760	330	5,333	4.1
	Roanoke Tel Co	Chambers Cty.	552	152	3,632	3.2
	Tombigbee Comm's	Hodges	926	239	3,874	6.2
		NE Franklin	3,301	789	4,184	19.1
		SE Franklin	3,601	955	3,770	7.3
		Spruce Pine	1,591	333	4,776	3.4
		Vina	1,653	542	3,050	8.5
	Troy Cable	6	1,058	294	3,599	8.8
		7	2,045	408	5,012	7.8
		8	438	29	15,095	2.3
	Windstream	Camp Hill	370	43	8,604	2.4
		Odenville North	308	71	4,331	0.8
		Springville	162	17	9,502	0.4
		Alabama Totals & Average	32,063	6,869	4,668	
California	Charter	Bella Vista	715	60	11,923	1.9
		Brookside	934	243	3,842	0.1
		Country Meadows	2,166	314	6,897	0.1
		Darlene Road	816	7	116,567	0.2
		El Dorado Estates	1,477	276	5,352	0.1
		Foothill Terrace	490	327	1,497	0.1
		Kingswood Estates	1,210	120	10,083	0.8
		Los Alisos	1,300	451	2,881	0.1
		Monterey Manor	796	92	8,654	0.0
		Mountain Shadows	2,007	132	15,203	0.1
		Oxnard Pacific	1,726	171	10,093	0.1
		Plaza Village	658	178	3,699	0.0
		River Oaks	829	45	18,432	9.0
		Riverbank	299	43	6,956	0.2
		Soboba Springs	984	249	3,951	0.1
		Villa Montclair	548	64	8,567	0.0
	Cruzio	Equal Access Santa Criz	5,347	940	5,688	0.2

State	Provider	Project Name	Project Total $k	HH	$/HH	sq.mi.
California	Frontier	Crescent City	1,587	134	11,842	0.1
		Cuyama	12,463	131	95,136	34.0
		Garberville	3,776	106	35,625	4.4
		Herlong	7,669	273	28,091	15.3
		Knights Landing	4,591	148	31,019	0.4
		Lake Isabella	9,595	946	10,143	7.4
		Mad River	8,170	266	30,714	23.0
		Northeast Phase 1	12,323	1,291	9,545	285.3
		Northeast Phase 2	10,359	1207	8,582	44.7
		Piercy	7,797	881	8,850	22.5
		Smith River	1,428	55	25,972	1.0
		Taft Cluster	2,562	265	9,667	65.0
	Hunter	Hoopa Valley	8,233	1,254	6,566	143.8
		Mendocino County	290,328	5,894	49,258	520.0
	Karuk Tribe	Klamath River	26,045	600	43,408	400.0
	Plumas-Sierra Tel	Elysian Valley / Johnstonville	3,972	84	47,282	3.0
		Eureka-Johnsville	1,601	83	19,294	6.0
		Keddie	1,512	39	38,773	3.0
		Lake Davis	2,777	185	15,011	6.0
		Long Valley	4,118	54	76,264	1.3
		Mohawk Valley	2,271	108	21,028	8.2
		Scott Road	4,307	37	116,418	32.8
		Sierra Valley	5,123	235	21,801	29.1
		Southern Lassen	13,631	932	14,625	32.1
	Race	Gigafy Arbuckle	4,241	482	8,799	0.3
		Gigafy Backus 2	4,703	266	17,679	8.1
		Gigafy Nevada City	6,155	499	12,334	8.5
		Gigafy Williams	6,759	588	11,495	0.5
	WiConduit	West Sonoma County	81,886	1342	61,018	2.9
		California Totals & Average	572,284	22,097	25,899	
Michigan	Ace Telephone	Mesick	5,383	484	11,122	34.0
	AcenTek	Iron Fish (Manistee)	497	57	8,725	1.1
	Charter	Cedar_Springs	2,523	467	5,403	6.6
		Durand	481	95	5,058	0.5
		Hale	444	78	5,694	0.4
		Kingsley	186	36	5,175	0.2
		Pellston	691	148	4,670	0.6
		West_Olive	385	87	4,431	0.2
	Comcast	Armada	3,394	451	7,525	17.8
		Buchanan	350	35	10,000	17.2
		Grattan	2,345	253	9,270	3.6
		Washtenaw	3,898	480	8,120	13.3

State	Provider	Project Name	Project Total $k	HH	$/HH	sq.mi.
MI, cont'd	Duke Broadband	Cottrellville	679	462	1,471	21.4
		Ira Exchange (St. Clair)	1,343	366	3,669	11.8
		St_Clair	1,522	1,083	1,405	42.0
	LakeNet	Lakefield_to_Jonesfield	1,289	373	3,457	38.5
		Richland_to_Jonesfield	1,675	342	4,899	35.0
	Springport Telephone	Duck_Lake_and_Springport	1,311	832	1,576	1.7
		Springport_to_Duck_Lake	716	50	14,323	1.7
	Upper Peninsula Tel. Co.	Wallace-Carney Exchange (Menominee)	4,339	695	6,243	23.8
		Michigan Totals & Average	33,452	6,874	4,867	
Nebraska	ATC Communications	North Arapahoe Holbrook	738	30	24,597	180.7
	Consolidated Tel Co	Hyannis	648	198	3,274	0.8
		Thedford	557	179	3,113	0.9
	Cox Nebraska Tel. LLC	Amended W of Fremont along Platte	1,246	83	15,009	2.4
		County Rd 33-1	431	28	15,383	1.4
		Springfield RDOF	2,577	98	26,299	4.1
	Glenwood Telecoms Inc	Fillmore County	2,891	248	11,659	9.2
	Great Plains	Beebe Seed Farms	260	9	28,861	1.9
		Dinklage	193	5	38,542	2.1
		Stockade	90	8	11,264	0.2
		Wausa Rural	1,989	78	25,500	62.9
	Hartington Telecom's Co	North Star	1,752	118	14,848	11.4
	Mobius Communications	Dawes County	1,975	106	18,634	79.0
		Mobius_NBBP Box Butte 22	3,150	128	24,609	83.9
		Mobius_NBBP_FT ROB.SIOUX 22	480	19	25,263	0.7
	NE Nebraska Tel. Co.	Antelope County	1,804	111	16,251	71.7
		Dakota County South of Hubbard	1,646	76	21,663	27.8
	Nebraska Central Tel. Co.	Arcadia Village Limits Underserved	411	197	2,087	0.6
		Burwell City Limits Underserved	1,230	414	2,971	0.3
		Rural Ravenna Underserved	437	29	15,076	2.3
		Rural Unserved w/ No Federal Support	2,269	126	18,005	31.5
	Pinpoint Comm's Inc	Nemaha County	1,741	98	17,763	21.7
		Rural South Lake Maloney	1,665	85	19,593	23.6
	Three River Commu's	Ainsworth Rural Fiber Upgrade	804	102	7,887	24.4
	Vyve Broadband	Tarnov Expansion	135	41	3,303	0.2
		Nebraska Totals & Average	31,120	2,614	11,905	
Virginia	BARC	Central Shenandoah, Rockbridge/Bath	17,836	1,085	16,439	12.5
	CenturyLink	Albemarle County	1,942	837	2,320	7.2
		Green County	475	320	1,484	5.1
	Comcast	Charles City County	5,288	2,350	2,250	39.0
		Frederick County	1,330	313	4,248	6.0
		Hanover County	1,442	292	4,939	3.4
		Page County – Overlook	445	108	4,116	2.2

State	Provider	Project Name	Project Total $k	HH	$/HH	sq.mi.
VA, cont'd	Cox	Gloucester County	564	68	8,288	0.4
		New Kent County	394	83	4,749	0.8
	Hosted Backbone	Orange County — BLM	2,666	918	2,904	2.7
	iGo	IDA of Russel County	2,984	705	4,232	5.7
	Lumos	Botetourt County	3,116	546	5,706	36.0
	Madison Gigabit	Orange Cty, Barboursville	2,041	590	3,459	10.6
	Mecklenburg Electric	Brunswick County	810	388	2,089	2.3
		Mecklenburg County	172	49	3,516	0.4
	Mendota	Washington County	2,668	589	4,530	40.0
	MGW Networks	Augusta County	1,112	494	2,251	1.6
	Point Broadband	Cumberland PDC - Bear Pen	1,309	189	6,924	2.2
		Cumberland PDC - Davenport	755	489	1,544	9.6
	Riverstreet	King and Queen County	17,262	3,832	4,505	304.4
		Virginia Totals & Average	64,610	14,245	4,536	
			$k	**HH**	**$/HH**	
		5-State Totals & Average	733,530	52,699	13,919	