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Aerospace & Defense, US Telecom & Communications Infrastructure

SpaceX: More on Direct-to-Device Mobile - what would a buildout cost? Our detailed bottom-up estimates


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We continue to be optimistic about the overall SpaceX opportunity (launch, orbital data centers, Starlink broadband for consumers, enterprise, and government customers). This combination has led to our positive outlook for SpaceX stock. But, the one business that we have viewed as the most difficult is the direct-to-device mobile business. SpaceX plans to begin Starship launches of its Mobile V2 satellite constellation in mid-2027. We described the challenges for SpaceX of going it alone, without a terrestrial partner, in our recent report, "SpaceX: The Telecom Play - Can Direct-to-Device Work?". Here, we take that work to the next level: examining what a SpaceX buildout would likely require and cost, as well as what the implications would be for players in the telecom and tower industries. This work has been led by our US Communications Infrastructure and Telecom teams, each with direct industry experience in terrestrial buildouts.

We estimate the cost of a terrestrial greenfield network build between $50-$130B inclusive of spectrum costs (~$15-$80B exclusive). This equates to ~30k-120k macro sites. The case swings wildly based on two decisions: (1) how aggressively does SpaceX want to compete with terrestrial providers on network quality, and (2) does SpaceX buy the 10MHz of low-band spectrum that Grain will soon auction. Elon commented in an X post "not true" in reference to the Bloomberg article, which said that SpaceX was looking at acquiring the Grain spectrum. But, our understanding is that while Elon may object to the content of the article, a Grain spectrum acquisition is not off the table. AST Mobile (not covered) is also eyeing the spectrum; the FCC granted them a 30-day special temporary approval to test supplementary coverage on it in their August 14 broadband deployment report.

Using those two levers, we have modeled **six scenarios**: a bare-bones metro network covering ~70% of POPs ("Metro", reminiscent of the DISH build), a "National" build that is more Sprint-like, but could be credible at the right price point, and a fully loaded premium network, approaching competitiveness with existing telcos ("Premium"). Each of those scenarios is modeled with and without the addition of Grain spectrum. **We would guess the most likely (of the unlikely) is a National build with the addition of Grain's spectrum: ~$70B and 57k macro sites over an ~8-year build period.**

For those of you who don't think about spectrum all day, allow us to translate: Grain's holdings represent a way to dramatically increase the efficiency and lower the cost of a new network build. **Having low-band spectrum (even a little bit) saves SpaceX ~30% of sites, and Grain has the only obviously available low band spectrum.**

To be clear, we still believe SpaceX is most likely to end with a partnership for its Mobile business. But, the company continues to indicate a terrestrial buildout i
continue to hear large numbers discussed by investors, especially in th
and towers, we wanted to provide a detailed assessment. For those wa
deep, here's our 15-tab model.



See the Disclosure Appendix of this report for required disclosures, analyst certifications and other important information. Alternatively, visit our Global Research Disclosure Website.

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BERNSTEIN TICKER TABLE

			28 Aug 2026		TTM	Adjusted EPS				Adjusted P/E (x)		
Ticker	Rating	Cur	Closing Price	Price Target	Rel. Perf.	Cur	2025A	2026E	2027E	2025A	2026E	2027E
SPCX (SpaceX)	O	USD	141.50	248.00	NA	USD		(0.20)	1.30		(716.0)	108.6
AMT (American Tower)	O	USD	176.23	214.00	(31.6)%	USD	5.40	7.01	6.93	32.6	25.1	25.4
CCI (Crown Castle)	O	USD	76.14	96.00	(40.7)%	USD	1.02	2.01	3.22	74.9	37.9	23.7
SBAC (SBA Comm)	M	USD	190.95	219.00	(25.9)%	USD	11.76	8.81	9.57	16.2	21.7	20.0
T (AT&T)	O	USD	26.01	25.00	(28.7)%	USD	2.12	2.35	2.68	12.3	11.0	9.7
CHTR (Charter)	M	USD	153.62	150.00	(60.3)%	USD	36.20	38.98	40.75	4.2	3.9	3.8
CMCSA (Comcast)	M	USD	27.06	28.00	(32.6)%	USD	4.30	3.40	3.85	6.3	8.0	7.0
TMUS (T-Mobile)	M	USD	181.37	220.00	(46.2)%	USD	9.72	10.68	13.24	18.7	17.0	13.7
VZ (Verizon)	M	USD	50.10	47.00	(4.6)%	USD	4.68	5.00	5.20	10.7	10.0	9.6
SPX			7,711.76									

O - Outperform, M - Market-Perform, U - Underperform, NR - Not Rated, CS - Coverage Suspended

Source: Bloomberg, Bernstein estimates and analysis.

INVESTMENT IMPLICATIONS

We rate SpaceX Outperform, with a target of $248.

We maintain our Outperform rating for T (PT: $25), and Market-Perform rating for VZ (PT: $47), TMUS (PT: $220), CMCSA (PT: $28), and CHTR (PT: $150) - all unchanged.

We maintain our Outperform ratings for AMT (PT: $214) and CCI (PT: $96) and our Market-Perform rating for SBAC (PT: $219).

DETAILS

PM SUMMARY

We've seen estimates for a SpaceX greenfield network build from $15B to $200B, but not yet a great, detailed bottom-up build. The most common approaches to use Dish's build and inflate a little. Dish spent ~$7.4B of cash capex between 2020-2024 for ~24k sites and ~268M pops (all spectrum costs + interest excluded). But there were two major differences between what Dish had/was doing and where SpaceX is today. First, Dish's build was primarily about meeting FCC coverage requirements cost-effectively to maintain spectrum licenses; it was never intended to support a real mobile subscriber base. Secondly, Dish was holding ~20MHz of nationwide 600MHz spectrum that could act as a low-band coverage layer - that was purchased by AT&T in July. The impact of using the Dish proxy is that most analyses therefore dramatically undercount both the absolute sites and cost of a new SpaceX build.

Mobile networks require two different types of considerations: **coverage** (does the service work as you move around, how far into the rural areas) and **capacity** (how many subscribers and how much traffic can the network support in a more congested area). For today's telcos, the conversation is all about capacity - coverage layers were built years ago - but for a new entrant, coverage is the dominant consideration.

Coverage is effectively defined by how many sites you have (could be towers or small cells) and how far your spectrum propagates. Using low-band spectrum, you can cover a wider radius - it won't support as many subscribers, but you don't care because you can cover more physical area. Think of it as a wide, shallow river. As you move into mid- and high-band spectrum, you have higher throughput and can support more traffic, but the signal doesn't propagate as far - the river is now a deep, skinny stream. Great for a capacity build, not so much for coverage. SpaceX's big hurdle is that they don't own any low-band spectrum today and there is only 10MHz available anywhere (the Band 26 that Grain currently owns).

In this analysis, we've gone deep on five areas:

1. Coverage requirements, including detailed population density and morphology modeling, with an incremental covered POP analysis.
2. Capacity requirements, inclusive of femtocell network offload proprietary to the SpaceX network design
3. Spectrum holdings and benchmarking on approximate cost ($/MHz-pop)
4. Detailed cost assumptions for both capex and Opex on a per-site and network-wide basis
5. Model validation against known build benchmarks, including Dish's unit costs and existing carrier metrics

We have phased the model to account for spectrum availability, labor and site constraints, and incremental subscriber additions, estimating the time to complete a full build. However, for this analysis, we have not assessed the return on a full network build or the ongoing economics beyond network Opex (specifically relevant for our tower names).

EXHIBIT 1: **SpaceX Greenfield Network Build Scenarios**

	Metro No Grain	Metro Grain	National No Grain	National Grain	Premium No Grain	Premium Grain
Terrestrial POPs coverage	70.0%	70.0%	92.0%	92.0%	95.0%	95.0%
Macro sites required [1]	**48,542**	**32,362**	**85,858**	**56,705**	**117,384**	**81,669**
POPs per macro site [2]	4,932	7,398	3,665	5,549	2,768	3,978
Program duration at max construction pace [3]	9	6	13	8	12	8
Network CAPEX (excl. spectrum) [4]	**$21.0**	**$14.3**	**$43.6**	**$29.7**	**$78.0**	**$55.9**
Spectrum (EchoStar + Grain + Upper C-band) [5]	$28.1	$32.6	$35.8	$41.8	$48.5	$57.0
Total Program Cost [6]	**$49.1**	**$46.9**	**$79.5**	**$71.5**	**$126.5**	**$112.8**
Subscriber ceiling before C-band, 2028-30 [7]	14.6%	10.3%	24.6%	17.3%	43.1%	32.2%
Marginal capex per incremental POP, coverage step alone [8]	-	-	$79.6	$79.6	$345.5	$345.5

1. T-Mobile runs ~82,000 macro sites and covers ~98% of Americans. DISH built ~25,000 and reached 80%.

2. Incumbents run 4,000-6,000. DISH ran ~10,700 and could carry only ~17% of its own subscribers on-net.

3. Capped by crews, zoning and utility interconnects, not by capital.

4. DISH spent $7.9bn ex-spectrum for ~25,000 sites - and never deployed a capacity layer.

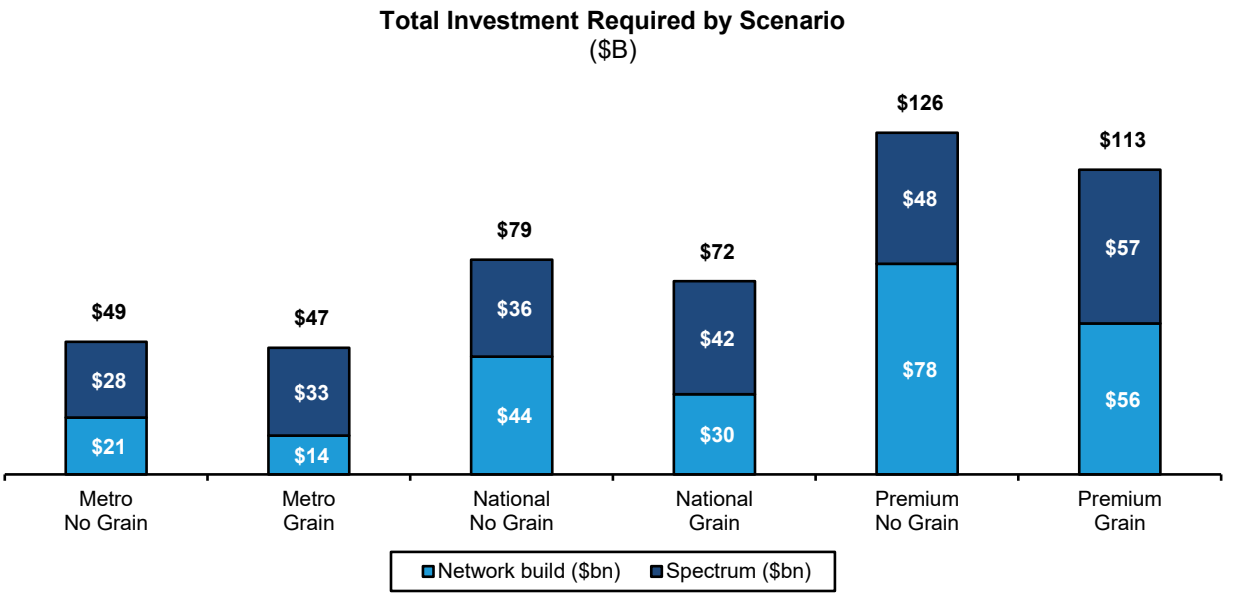
5. $21.6bn to EchoStar is already committed in every scenario. Grain adds $5-7.5bn where won; Auction 115 is sized to the build.

6. Excludes subscriber acquisition, handsets, retail and the satellite constellation. Grain reduces cost in every pair despite adding spectrum cost.

7. As penetration of covered POPs. This is the network SpaceX actually operates until the very end of 2030.

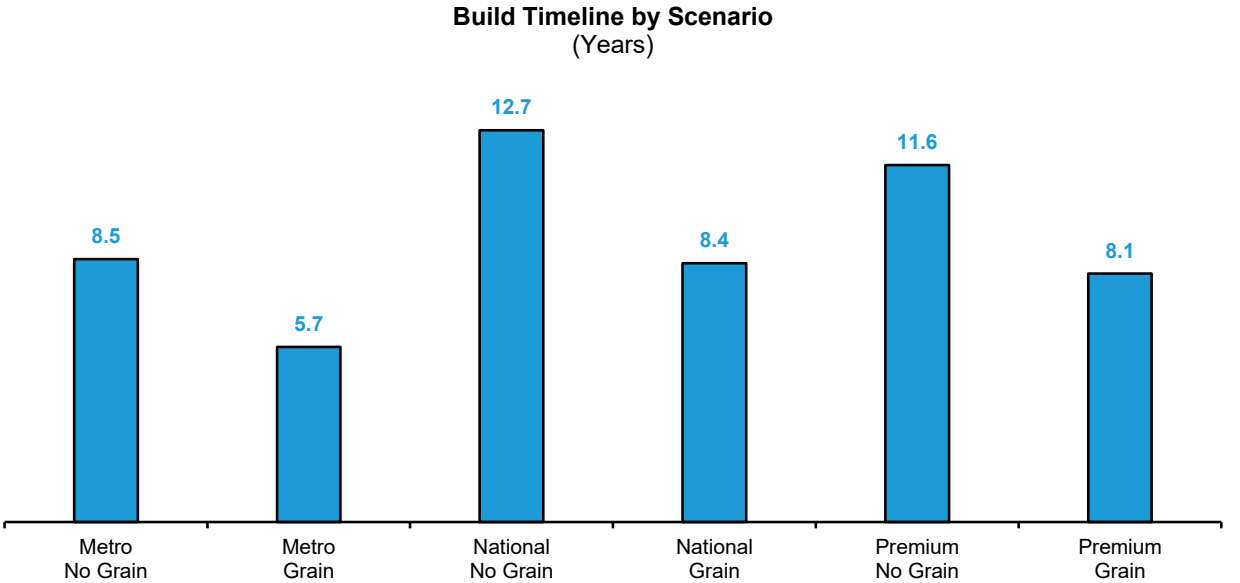
8. The National columns isolate the 70-to-92% step; Premium the 92-to-95% step.
Source: Bernstein analysis and estimates

EXHIBIT 2: **Total Investment Required by Scenario ($B)**



Grain decreases cost in every case, despite adding $5 - $7.5bn, because it reduces more the buildings than it adds to the licence.

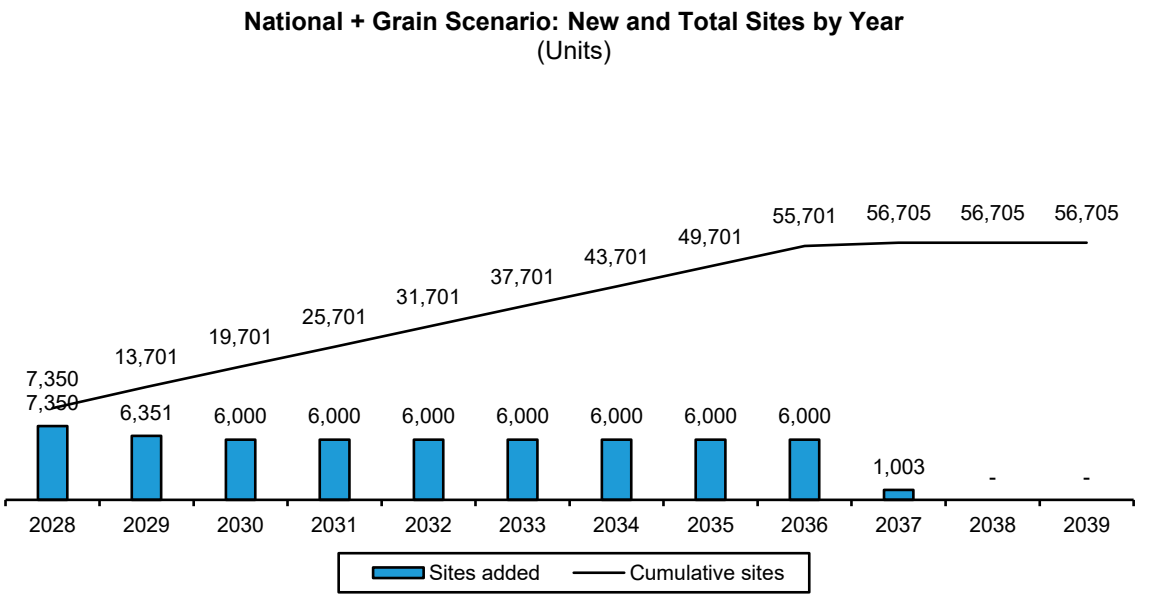
EXHIBIT 3: **Build Timeline by Scenario (Years)**



Construction capacity, not capital, is the binding constraint. The US builds only 1,200-2,000 genuinely new towers a year in total, the model assumes the build sits almost entirely on existing structures.

Source: Bernstein analysis and estimates

EXHIBIT 4: **National + Grain Scenario: New and Total Sites by Year (Units)**



Source: Bernstein analysis and estimates

A REMINDER ON WHY A TERRESTRIAL NETWORK IS ESSENTIAL

There are ongoing debates about the capabilities of Starlink's next-generation V2 mobile satellites. Relative to the current constellation, the new satellites are expected to have larger antennas, greater capacity, denser beamforming, and lower operating altitudes, all of which should improve link budges, spectral reuse, and the number of concurrent users. While there are still many unknowns (e.g., spectrum, network demand, interference management, realized throughput), it is reasonable to envision a scenario where basic downlink-centric experience, such as receiving notifications, loading web content, browsing social media outdoors, become increasing practical.

However, as we discussed in our prior note, the more fundamental challenge for D2D remains the Uplink, particularly for applications requiring continuous two-way communication such as voice/video calls, or a future AI-connected ecosystem. Lower orbital altitudes and more capable satellites can improve Uplink performance, but they do not eliminate the basic constraint that a handheld device has limited transmit power, antenna gain, and battery capacity. This challenge becomes even more difficult indoors, where building penetration losses can substantially degrade the signal before it ever reached the satellite. As a result, improvements in downlink performance address only part of the problem. The broader question remains whether D2D can ultimately deliver sufficiently reliable uplink performance across environments and use cases to evolve from a complementary coverage solution into a true substitute for terrestrial cellular networks.

OUR MODELED SCENARIOS

Since there is still significant debate about SpaceX's goals with their future mobile network, it's hard to define what kind of network they would build. For our purposes, we've looked at three options:

- **Metro Network, covering 70% of POPs:** We view this as a relatively unlikely outcome and a low case for capex numbers. Under this scenario, we assume SpaceX only attempts to cover 70% of POPs, with most of its concentration in Dense Urban and Urban locations, prioritizing network quality only to outdoor and in-vehicle design. We assume coverage of ~20% of rural arterial (beyond interstates), and very limited overshoot beyond the road polygons. Translation: this would be a very crappy network that would not compete well against existing carriers, even at a steep discount - it represents the bare minimum option for SpaceX to offer mobile service.

- **National Network, covering 92% of POPs:** This is our base case and would look similar to a Sprint-type network. Competitive enough in many areas for a proof-of-concept while they scale, okay coverage beyond the interstate corridor (~45% relative to the 20%), better in-building coverage and support for ~50-75M subscribers. In this scenario, SpaceX could be credible and perhaps even differentiated in certain areas with the augmentation of ever-evolving D2D tech. We model incremental 40MHz of Upper C-band spectrum to further enhance the network.

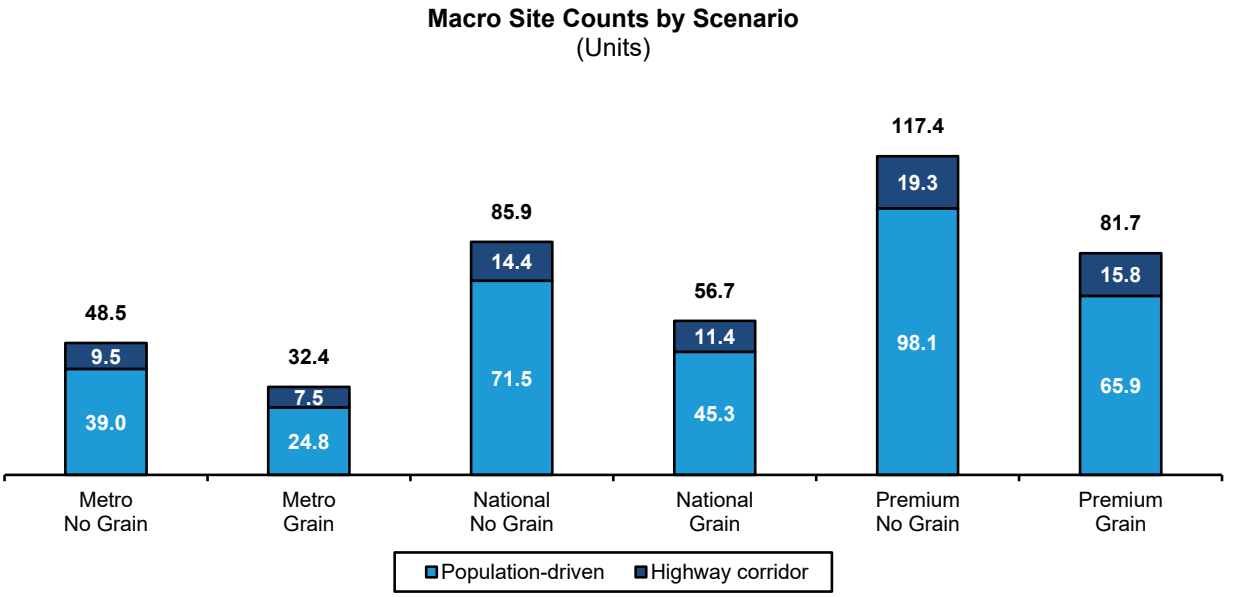
- **Premium Network, covering 95% of POPs:** Our high case and approaching full network parity with existing carriers across several metrics. This case requires spectrum purchases between $50-70B and 80-120k sites, rivaling TMUS's 82k nationally. As in the other cases, we assume sizable offloading of terrestrial network needs to the satellite network where possible, via femtocells, satellite tower backhaul, and D2D - it shows up more meaningfully in a premium build given the sheer site volume. We also assume antennas are more expensive, labor costs increase given scarcity, and a slightly compressed build timeline consistent with aggressive goals.

EXHIBIT 5: **Assumptions Overview by Scenario**

	Metro Build	National Build	Premium Build
Network Build Inputs			
Terrestrial POPs coverage target	70%	92%	95%
Share of rural arterials targeted for coverage	20%	45%	70%
Land area covered (sqmi)	68,519	235,671	310,563
Max outdoor small cell adds per year	10,000	30,000	50,000
Traffic per subscriber per month (GB)	30	38	48
Downlink to uplink traffic ratio	10.0	8.0	6.0
Upper C-band MHz won at Auction 115	20	40	60
Total MHz held	85	105	125
SpaceX share of covered POPs at maturity	5%	8%	12%
Output Metrics (all scenarios without Grain spectrum)			
Macro Sites required	48,542	85,858	117,384
Small cell nodes	23,802	39,693	87,253
POPs per macro site	4,932	3,665	2,768
Capex per POP covered	$87.75	$138.66	$240.11

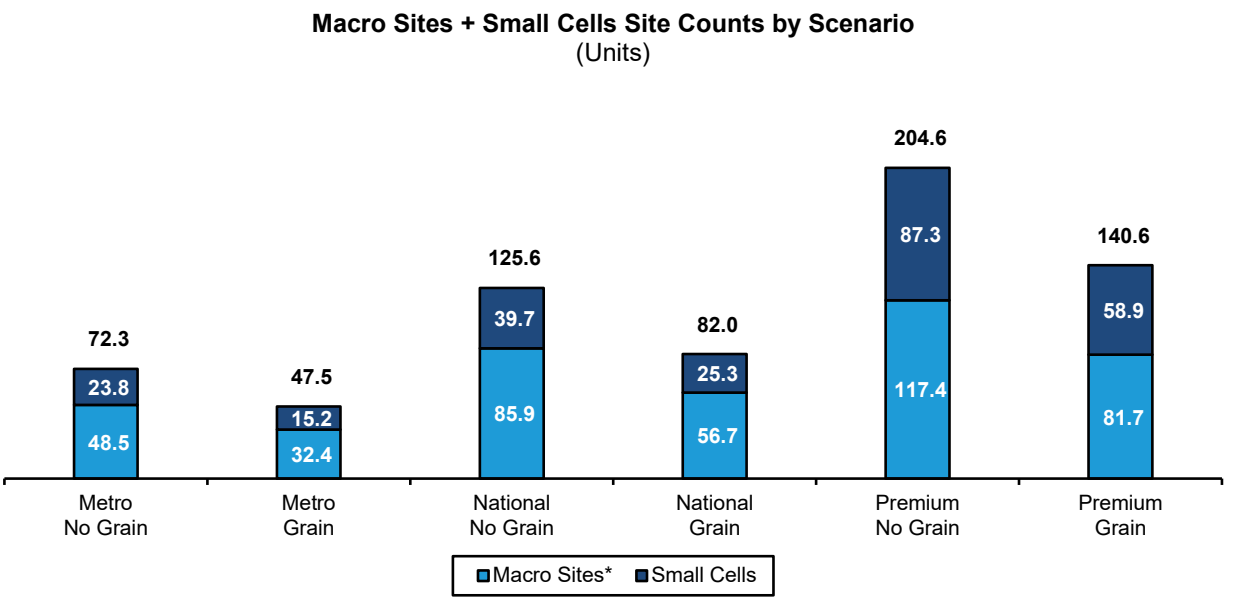
Source: Bernstein analysis and estimates

EXHIBIT 6: **Macro Site Counts by Scenario (Units)**



Split between the sites needed to reach people and the sites needed to cover the highways between them
Source: Bernstein analysis and estimates

EXHIBIT 7: **Macro Sites + Small Cells Site Counts by Scenario (Units)**



* Population-Driven + Highway Corridor
Source: Bernstein analysis and estimates

NETWORK BUILD: COVERAGE REQUIREMENTS

Most of the site-count numbers circulating on SpaceX start with a site count and multiply by a cost per site. Ours starts with where Americans actually live, asks how far a radio signal reaches in each kind of place at each candidate frequency, and then calculates the tower count from that geometry. The most essential thing to understand about coverage builds is that an incremental covered POP gets increasingly expensive as you move out from the densely populated areas. ~70% of the population has similar incremental costs, but then there are clear cutoffs as you expand into more and more rural areas. In other words, your POPs per square mile fall ~40x between the urban core (~940) and the rural blanket (~24). This is what makes nationwide coverage so expensive. Added to that, you don't just have to cover where people work and live...you have to cover the rural highways in between. Yes, in theory you could have a roaming or MVNO deal to eventually lower these costs, but today, that's not in place.

HOW WE MODELED IT:

We anchored the population-versus-land curve on the 2020 Census Urban Areas file — 2,613 urban areas, 265,149,027 people, 80.0% of the US population on 103,872 square miles, or 2.94% of US land, We then split the urban 80% using the Center for Neighborhood Technology's density thirds off ACS (American Community Survey) 2017-21 block groups. That lays the population into **nine cumulative bands rolled up into four morphology tiers -** RF behavior and cost structure tend to differ by tier, not by band.

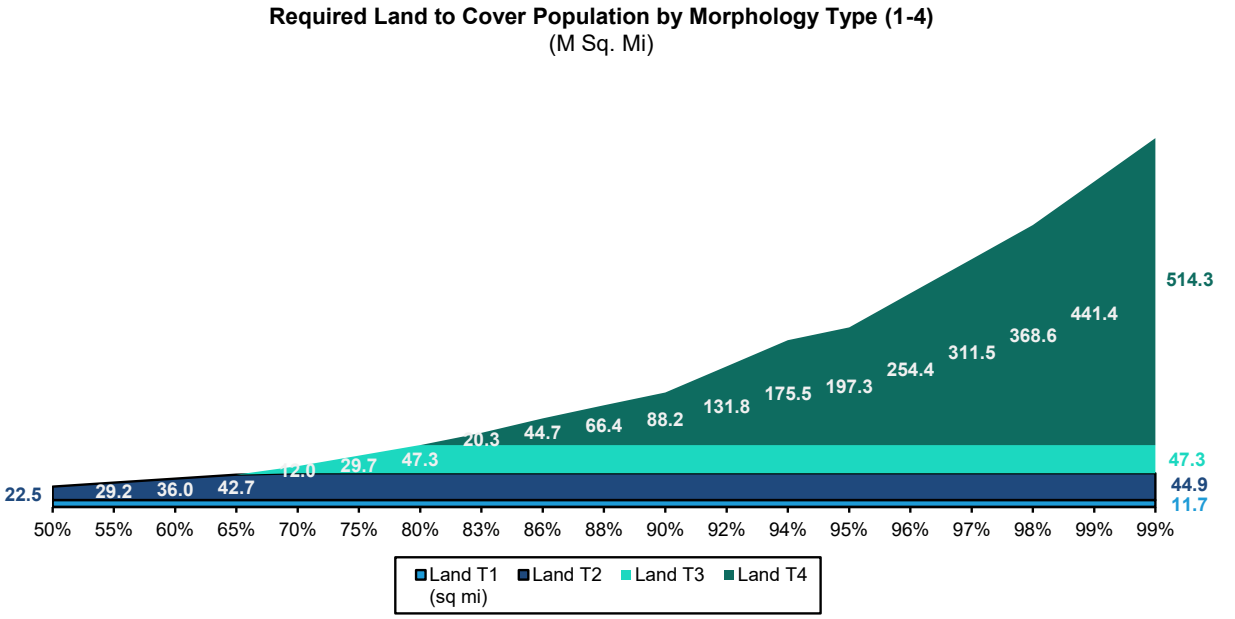
Above 80% of POPs the Census gives no continuous function, so bands 4-9 come from probit interpolation between the verified anchors on the standard assumption that log density is approximately normally distributed across space; ±30% on rural land area moves the National site count only 6.9%, so while you could do a more detailed analysis on this, we didn't think it was meaningful for this case.

The corridor layer is sized off FHWA Highway Statistics 2023 Table HM-20: **29,109 rural Interstate miles plus 97,964 rural freeway and principal arterial miles — of which we target 20/45/70% by case, credit 45/55/65% as already covered incidentally by the population footprint, and uplift spacing 1.20-1.50x for terrain and shadowing, leaving residual polygon overshoot at 1.00-1.10x.**

Corridor coverage is a linear problem, not an areal one — sites along a road scale with radius, not radius squared — so we hold that layer constant across the coverage build. This adds 11,413 sites in the National Grain case, roughly 24% on top of the population-driven grid.

Note: unlike previous coverage builds, there is no regulatory floor: the FCC waived SpaceX's AWS-4/H-block/AWS-3 terrestrial buildout obligations entirely (DA 26-471, 12 May 2026) and replaced them with satellite D2D performance metrics. At this point, coverage is purely a commercial decision.

EXHIBIT 8: **Required Land to Cover Population by Morphology Type (1-4) (M Sq. Mi.)**



Source: Bernstein analysis and estimates

EXHIBIT 9: **Coverage & Network Scenarios Overview**

Metric	Units	Metro No Grain	Metro Grain	National No Grain	National Grain
Terrestrial POPs coverage [1]	%	70.0%	70.0%	92.0%	92.0%
POPs covered	m	239.4	239.4	314.6	314.6
Total Macro Sites [2]	sites	**48,542**	**32,362**	**85,858**	**56,705**
Outdoor small cell nodes	nodes	23,802	15,151	39,693	25,262
Starlink-backhauled femtocells	units	1,500,000	1,500,000	4,000,000	4,000,000
POPs per macro site [3]	POPs	4,932	7,398	3,665	5,549
Colocations required on third-party towers	sites	42,717	28,479	76,414	50,467
New greenfield towers required [4]	sites	971	647	2,576	1,701
Program duration at maximum construction pace [5]	yrs	**8.5**	**5.7**	**12.7**	**8.4**
Network complete	year	2037	2034	2041	2037

1. No regulatory floor applies — the FCC waived SpaceX's terrestrial buildout obligations on 12-May-2026, replacing them with satellite D2D performance metrics.

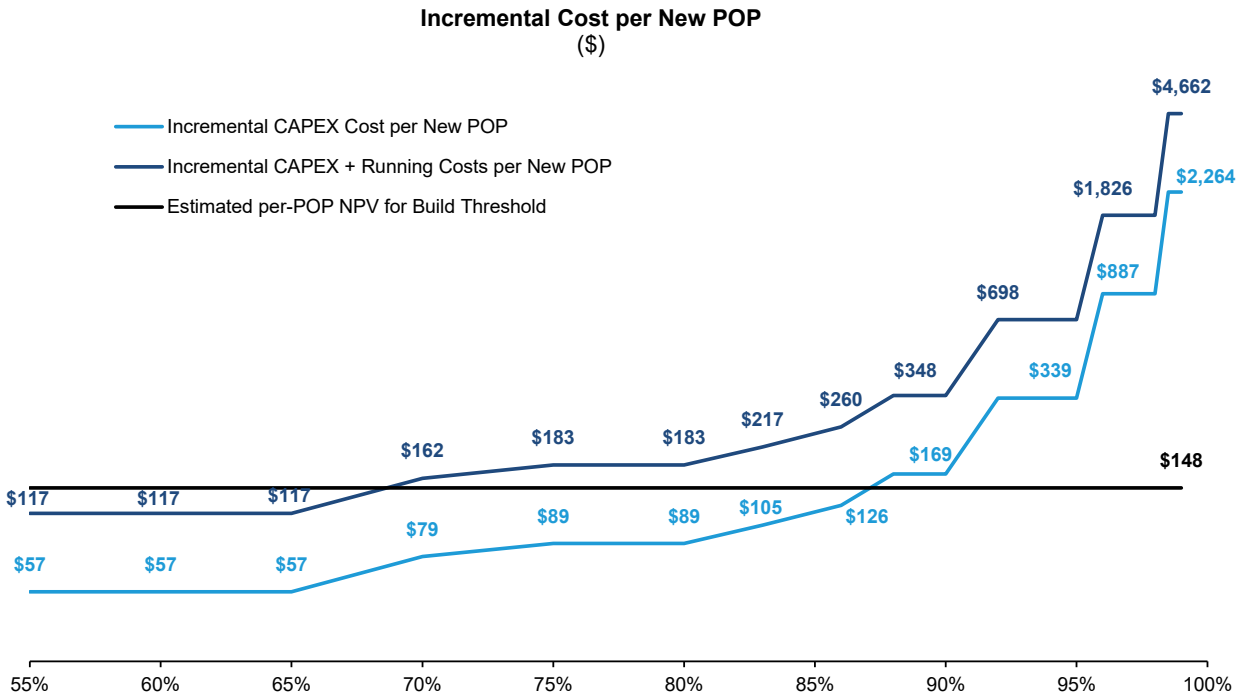
2. T-Mobile runs ~82,000 macro sites, reaching ~98% of Americans; DISH runs ~25,000, reaching 80%.

3.Incumbents run 4,000-6,000 POPs/site; DISH runs ~10,700 but carries only ~17% of its subscribers on-net.

4. Against total US new-tower capacity of ~1,200-2,000/year, of which ~25% isn't even wireless.

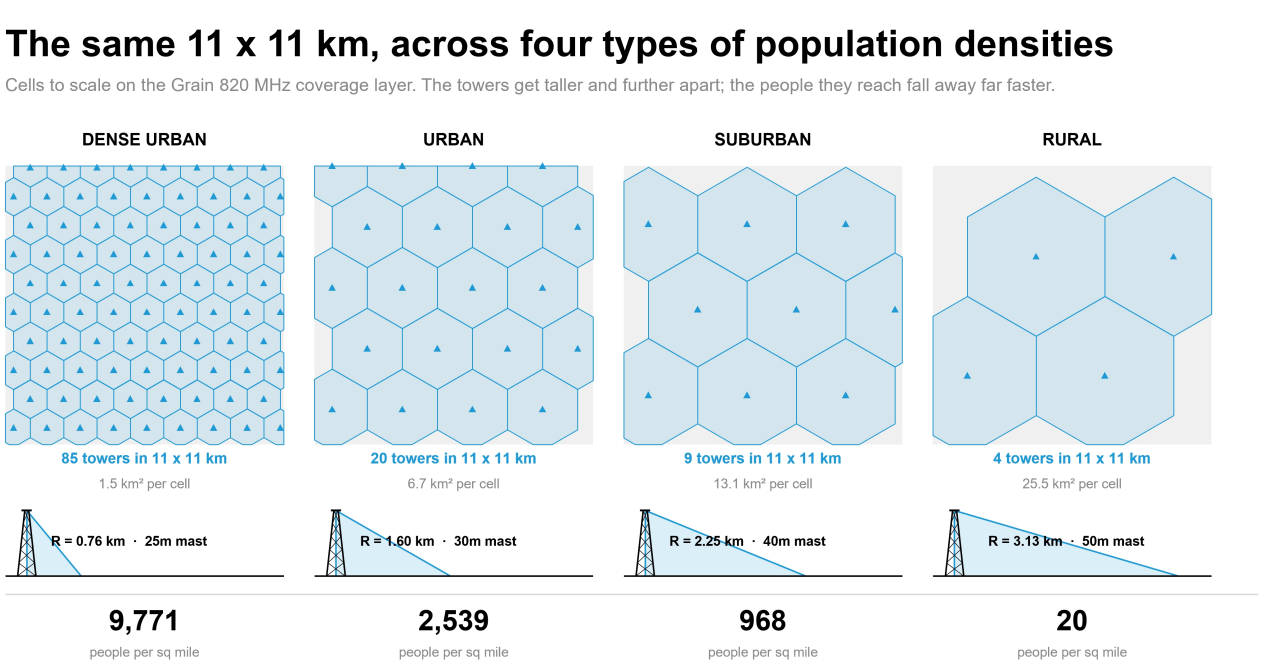
5. Capped by construction capacity, not capital — the constraint most published estimates ignore.
Source: Bernstein analysis and estimates

EXHIBIT 10: **Incremental Cost per New POP ($)**



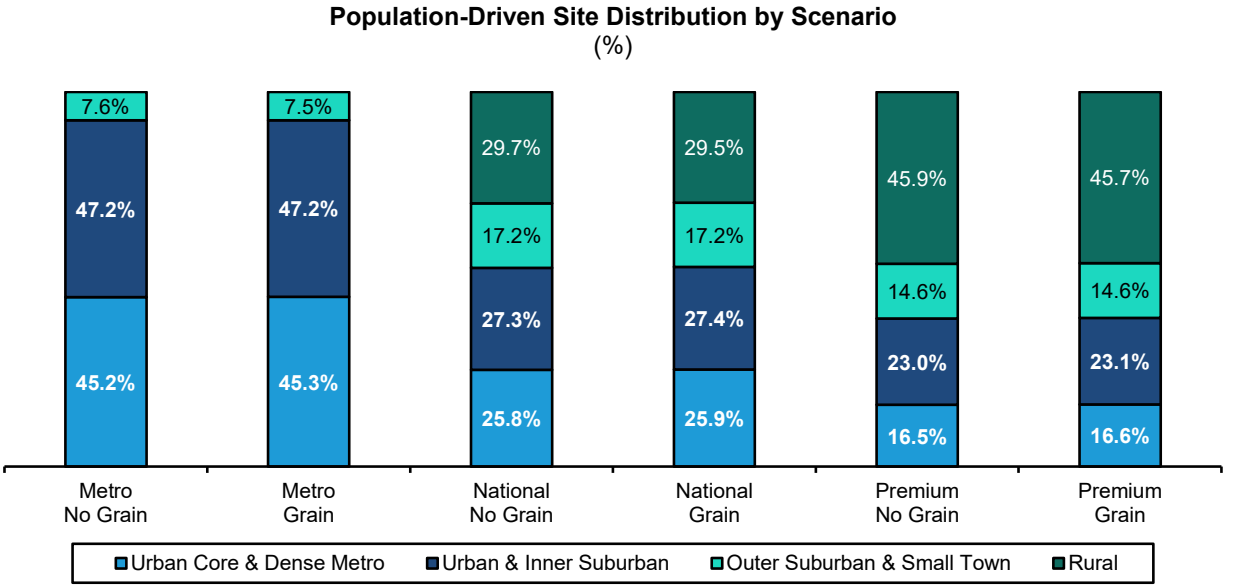
Source: Bernstein analysis and estimates

EXHIBIT 11: **Coverage by Population Sites**



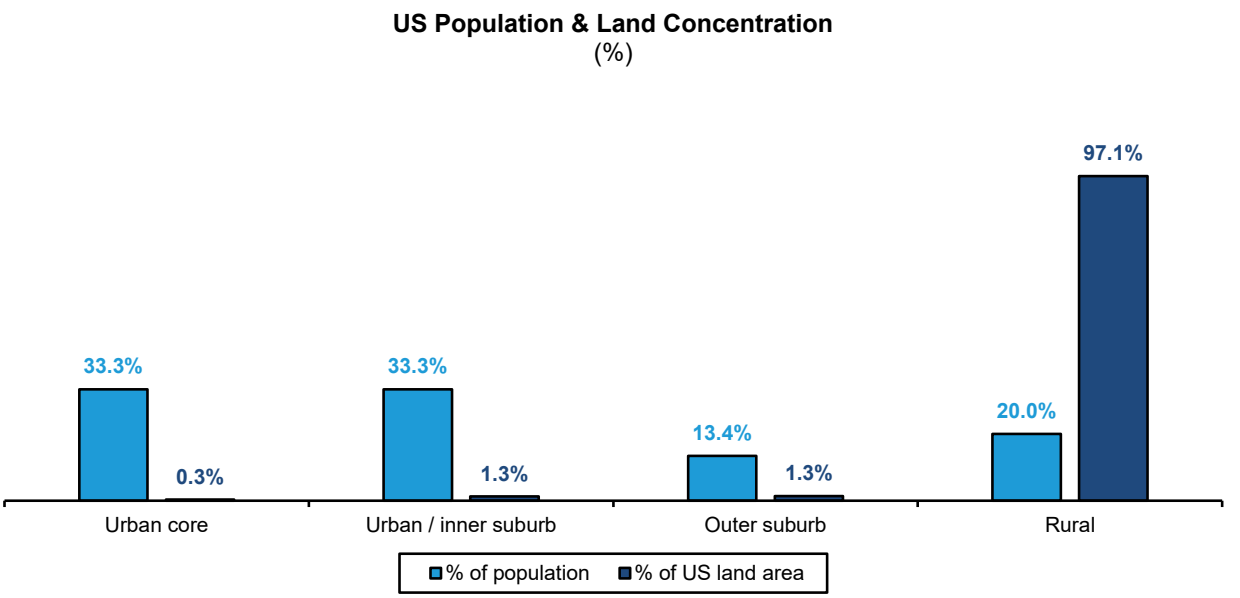
Source: Bernstein analysis and estimates

EXHIBIT 12: **Population-Driven Site Distribution by Scenario (%)**



Source: Bernstein analysis and estimates

EXHIBIT 13: **US Population & Land Concentration(%)**



More than 2/3 of the U.S. population is concentrated in less than 3% of total U.S. land area, making full land coverage increasingly challenging and subject to diminishing marginal benefits.
Source: Bernstein analysis and research

NETWORK BUILD: CAPACITY REQUIREMENTS

Coverage and capacity are two different problems. Coverage asks how far each tower reaches; capacity asks how many people can use it at once before it slows down (think of the moment your plane lands and everyone is trying to text at the same time). Build for reach, and you get whatever capacity happens to come with it — and on our numbers that turns out to be enough, for a while. On Day 1, Capacity isn't a concern - you have a very small number of subscribers and plenty of capacity in the network from your coverage build - 2-3.5x its target subscriber base across the entire thing. But subscribers concentrate just as the US population does, so before long, you need to add incremental capacity alleviation in your densest, most congested areas.

HOW WE MODELED IT:

For every geographic area we build two grids - a coverage and a capacity - and keep the larger number. The traffic-driven floor is set so that a dense urban grid spaced 1.5 km apart reproduces roughly 4,000-5,000 people per site, which is what T-Mobile actually runs across its 82,000 macro sites. In every scenario we test, reach is the binding constraint, not traffic. That is the whole thesis: SpaceX's spectrum is mid-band and its coverage layer is narrow, so the network runs out of range long before it runs out of room.

Sizing the traffic side is straightforward arithmetic in three steps. Take a subscriber's monthly data allowance and convert it into what they consume in the busiest hour of the day (we use 7% of daily traffic, the standard planning convention, because networks are dimensioned for the peak, not the average - we all use our phones at the same time). Then we compute what one tower can deliver — spectrum available, multiplied by how efficiently the radios turn hertz into bits, multiplied by three sectors, multiplied by a loading factor of 55-72% because no network ever achieves its theoretical maximum. Divide the second by the first and you have subscribers per tower.

But usage and uplink/downlink balance must be considered too. A tower's real capacity is the *worse* of its download and upload capability, not the download alone. A network that can push video down but not pull photos up is capacity-constrained in practice. We size this as the minimum of the two, and the counter-intuitive result is that uploads are not yet the pinch point for this build (this is likely to be an issue for existing networks, but we'll save that analysis for another day).

The large antenna arrays that boost the download also help the tower hear the handset, so uploads only become the constraint once traffic is more balanced than roughly 5:1 down-to-up. Today's US networks run 8-10:1, but that ratio is falling as video calling and cloud backup grow, so this build has about one halving of the ratio in hand before uploads bind on capacity as well as on coverage. We feel like it's important to flag that the capacity outputs are probably the least robust numbers in this analysis: if you knock spectral efficiency down a third, or run data-per-subscriber at the 2031 forecast rather than today's, and the pre-C-band ceiling falls from 16.5% of covered population to roughly 11%, but probably for today, we're in range.

SpaceX's stated ambition is not just towers. Shotwell and Musk have described putting "little femtocells" — small, self-installed licensed-band base stations — alongside the Starlink dishes already sitting on roughly 12m US premises, backhauling that traffic straight up to the constellation and bypassing the macro network entirely. It is a genuinely clever asset play, because the expensive parts are already paid for: the dish is installed, the customer installed it themselves, and the incremental hardware is much, much cheaper than an incremental small cell (or tower) build. ~90% of mobile usage indoors, and indoor traffic is precisely what a premises femtocell can absorb and precisely what a satellite beam cannot. So we model it as real capacity relief: 1.5m to 8m units by case, taking 4-18% of total traffic off the macro grid, plus a further 0.5-3.0% offloaded to direct-to-device satellite.

But we notably restrict where that relief is allowed to land. Femtocells and D2D reduce traffic in the urban and suburban tiers only, because that's where you have capacity constraints. A femtocell exists where a premises and a dish already exist; D2D carries messaging and low-rate traffic, on beams sharing a few Mbps across a footprint the size of a state. Neither one builds a cell on an empty stretch of highway in Wyoming. **The offload story unfortunately relieves the cheapest part of the build and leaves the expensive part - femtocells improve the capacity headroom without moving the tower count or the capital bill significantly, at least based on today's tech.**

EXHIBIT 14: **Site Count Overview**

	Metro No Grain	Metro Grain	National No Grain	National Grain	Premium No Grain	Premium Grain
Total Macro Sites (population + corridor)	48,542	32,362	85,858	56,705	117,384	81,669
of which: new-build (greenfield tower required)	971	647	2,576	1,701	5,869	4,083
of which: rooftop / non-tower structure	4,854	3,236	6,869	4,536	7,043	4,900
of which: colocation on an existing tower	42,717	28,479	76,414	50,467	104,472	72,685
Traditional Small Cells (may be Starlink-backhauled)	971	647	2,576	1,701	5,869	4,083
Starlink-backhauled femtocells deployed	1,500,000	1,500,000	4,000,000	4,000,000	8,000,000	8,000,000

Source: Bernstein analysis and estimates

EXHIBIT 15: **Capacity Metrics Scenarios Overview**

Metric	Units	Metro No Grain	Metro Grain	National No Grain	National Grain
Target subscribers [1]	m	9.6	9.6	25.2	25.2
Busy-hour demand per subscriber [2]	Mbps	0.149	0.149	0.166	0.166
Site capacity BEFORE Upper C-band [3]	Mbps	119	132	158	176
Traffic asymmetry at which the UPLINK becomes the constraint [4]	x	**5.6**	**5.2**	**5.4**	**5.1**
SUBSCRIBERS THE GRID SUPPORTS, 2028-2030	m	**35.0**	**24.8**	**77.3**	**54.5**
as penetration of covered POPs [5]	%	**14.6%**	**10.3%**	**24.6%**	**17.3%**
CAPACITY HEADROOM before C-band (ceiling / target) [6]	x	**3.7x**	**2.6x**	**3.1x**	**2.2x**
as penetration once Upper C-band is on air (2031+) [7]	%	**27.2%**	**18.3%**	**65.3%**	**43.2%**

1. Target penetration of covered POPs; Boost peaked near 2.7%, with 83% of that share coming from a single wireless network.

2. GB/month, converted to busy-hour traffic at 7% of daily volume, net of femtocell and D2D offload.

3. Low-band + 2 GHz layer, sized as the min of downlink/uplink capacity rather than downlink alone.

4. US mobile traffic today runs 8:10:1 downlink-heavy and is trending lower; once Upper C-band deploys, the crossover shifts to 5:6:1.

5. Versus the target penetration three rows up: DISH covered 268m POPs but carried only ~17% of Boost's on-net traffic, reflecting a thin grid and spectrum position.

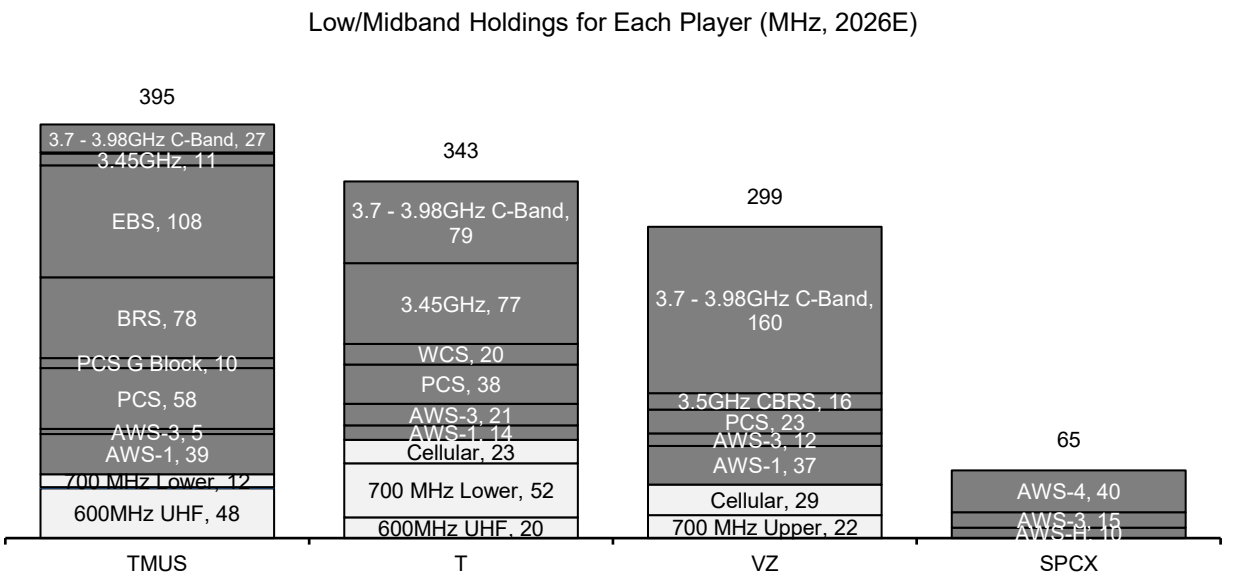
6. Headroom isn't binding today (2.1x-3.5x target), but at ~13% annual traffic growth per subscriber, 2.1x buys only ~6 years — against a 6-10 year build cycle. Grain also cuts headroom 25-30% per pair, since fewer sites mean less capacity.

7. C-band isn't optional — it's what determines whether the network can actually hold its subscriber base.
Source: Bernstein analysis and estimates

SPECTRUM CONSIDERATIONS

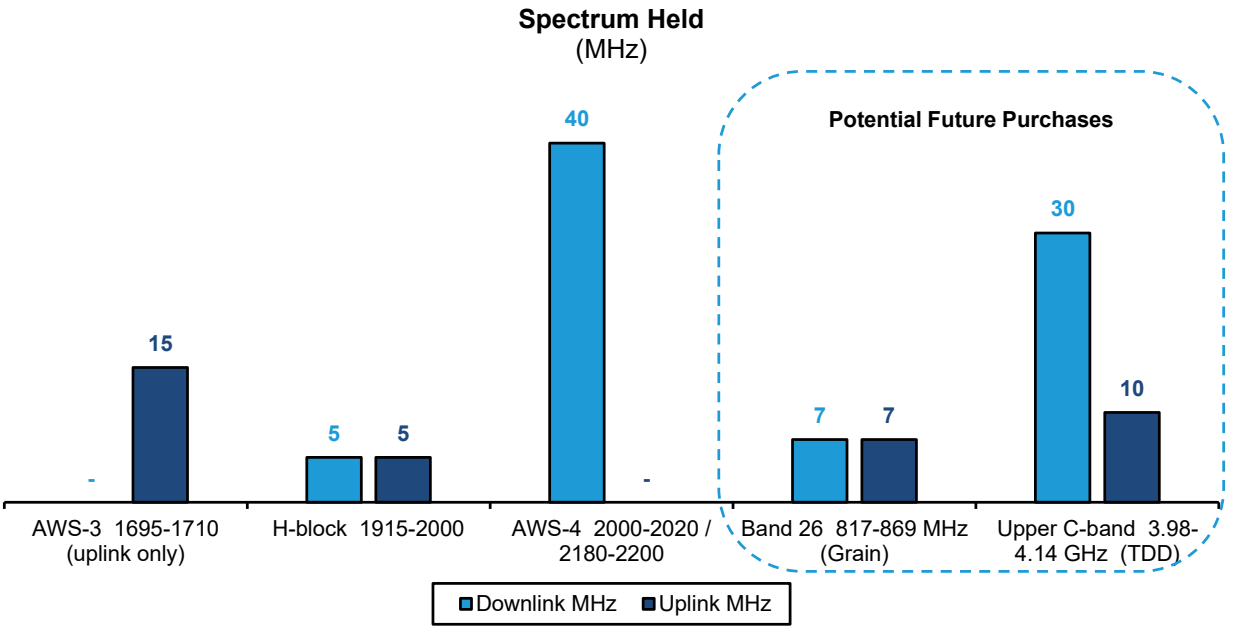
Spectrum is the crux of this entire case and perhaps the part least understood by investors. The spectrum bands dictate how far apart the towers can be in a coverage build, which as we mentioned, is really driving the numbers today. Spectrum is finite and expensive - it is only made available periodically through FCC auctions (each with different rules, geographic units, and timelines) or on the secondary market. Today, SpaceX holds ~65MHz; our scenarios have it reaching up to ~120MHz in a high case. This still pales in comparison to existing players, who have 300-400MHz of low- and mid-band spectrum.

EXHIBIT 16: **Spectrum Holdings fro T-Mobile, AT&T, Verizon, and SpaceX**



Source: Company Filings, SNL Kagan, FCC, Bernstein Research and Analysis

EXHIBIT 17: **Spectrum Held (MHz)**



Coverage is limited by the phone talking back to the tower, not the tower talking to the phone. A handset transmits at 0.2 watts against a tower's 40 watts, so it is the uplink column that sets how far apart towers can sit - and therefore how many are needed.
Source: Bernstein analysis and estimates

WHY LOW BAND IS ESSENTIAL

Low-band spectrum can cover a wide radius - it propagates further with a thinner layer - as opposed to mid- or high-band which has a shorter radius and a fatter pipe. SpaceX does not own any low band spectrum today, and its only apparent path to getting some is the Grain block being auctioned this fall. Low-frequency spectrum travels further before fading, and it penetrates walls and windows better — so the same handset, transmitting the same 23 dBm, reaches a tower that is meaningfully further away. Every incumbent US carrier has a low-band coverage layer underneath its network for exactly this reason: Verizon and AT&T on 700 MHz, T-Mobile on 600 MHz. SpaceX, as things stand, does not have one.

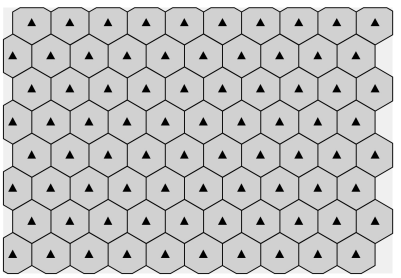
Halving the frequency does not quarter the tower count. In open air it roughly would, and models built on free-space assumptions still say so — which is how you end up with people quoting a 30x tower multiple for C-band against 600 MHz. In the real world, signals bounce off buildings and diffract around terrain, and the standard propagation models say the tower count scales close to linearly with frequency instead. We test that: if you rerun the identical engine at 600 MHz and the National build needs 43,685 towers against 88,563 at 1.7 GHz — a 2.03x difference on a 2.83x frequency change, nowhere near the 8x free-space thinking predicts. Low band is worth roughly a third of the tower count, not three quarters of it. **That is still the single largest swing factor in this analysis and the most important decision between our scenarios - whether SpaceX acquires low band spectrum or not.**

EXHIBIT 18: **Low-band Spectrum Overview**

Why low-band spectrum removes towers

Same area tiled based on spectrum propagation. Cells drawn to scale from the model's link budget.

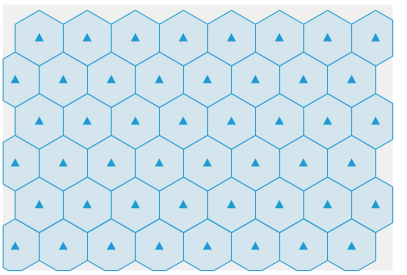
WITHOUT GRAIN
AWS-3 uplink, 1.7 GHz
The spectrum SpaceX holds today



80 towers

cell radius 2.49 km cell area 16.1 km²
inter-site distance 4.31 km

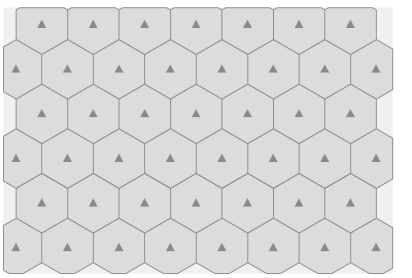
WITH GRAIN
Band 26 uplink, 820 MHz
Addition of the EchoStar 800 MHz portfolio



48 towers

cell radius 3.13 km cell area 25.5 km²
inter-site distance 5.43 km

WHAT DISH HAD (REFERENCE)
n71 uplink, 680 MHz
600 MHz, sold to AT&T in 2026



45 towers

cell radius 3.36 km cell area 29.3 km²
inter-site distance 5.81 km

Same area, different spectrum positions: 80 towers → 48 → 45. On cell area, Grain takes 37% of the rural grid away; 600 MHz takes 45%.

ISD = √3 x R and cell area = 0.866 x ISD², so area grows with the SQUARE of radius — but radius grows only roughly LINEARLY as frequency falls, so halving the frequency does not quarter the towers. Radius is derived from an uplink link budget inverted through 3GPP TR 38.901 (RMa NLOS, rural tier shown here), not assumed. Across the full national build the model puts the difference between the first two columns at 81,695 sites versus 53,400. The 600 MHz column uses the n71 uplink centre of 680 MHz, not the 600 MHz band label, and a 14.5 dBi panel interpolated on the model's own 17.5 / 15.0 dBi slope. The third column is a reference case, not a scenario in the model: DISH's 600 MHz went to AT&T in July 2026 and is not available to SpaceX.

Source: Bernstein analysis and estimates

SPECTRUM ACQUISITION OPTIONS: EXISTING HOLDINGS, GRAIN, UPPER C-BAND

For incumbents, the cost to acquire their current licenses (including mmWave) has been >$100B per player. Reproducing the spectrum holdings of the major wireless carriers would require hundreds of billions of dollars. That is, if the spectrum was available for sale. Arguably, the more important roadblock is finding the spectrum required to build a 4th terrestrial network in the first place. Much of the spectrum that can facilitate wireless service in the US is already used up either by incumbent carriers or other users for different applications. SpaceX's existing and potential spectrum position has three distinct components, each doing a different job.

1. The existing EchoStar holdings — committed, but the wrong shape.

SpaceX is acquiring AWS-4 (40 MHz), H-block (10 MHz) and unpaired AWS-3 (up to 15 MHz) from EchoStar, 65 MHz in total, for roughly $20bn plus about $2bn funding EchoStar's debt interest through November 2027. The FCC approved it on 12 May 2026 (DA 26-471), though the spectrum sits in a trust until closing targeted for 30 November 2027. Here is the problem: only 20 MHz of it is usable *upload* spectrum — 15 MHz at 1695-1710 and 5 MHz at 1915-1920 — against 45 MHz of download. The 2180-2200 MHz download band has no matched upload pair anywhere in the portfolio, because the AWS-3 pair at 1755-1780 went to Verizon, T-Mobile and AT&T at Auction 113 in June 2026. **So SpaceX owns a portfolio whose coverage reach is governed by 1.7 GHz — mid-band, with mid-band propagation — and a 2.25:1 download-to-upload asymmetry it cannot fix by buying more of the same.**

2. Grain's 800 MHz — the coverage layer SpaceX doesn't have, and doesn't yet own

This is the asset that changes the build costs meaningfully. Band 26 at 817-824 MHz paired with 862-869 MHz is genuine low band. It drops the coverage layer from 1.70 GHz to 0.82 GHz, stretching the rural cell radius from 2.49 km to 3.13 km, and **cuts the National build from 88,563 towers to 58,423.** Roughly 10 MHz is deployable as a contiguous carrier, which is ample for coverage — cell-edge planning uses a 1.44 MHz upload grant — but carries almost no capacity, so the other bands still have to do that work. It is a coverage asset, full stop. Grain bought the portfolio from T-Mobile on 11 August 2026 for $2.9bn cash plus its own 600 MHz licenses, roughly $3.6bn all-in. Before T-Mobile, this was Sprint's coverage layer...a bit of a full-circle moment for the telecom geeks.

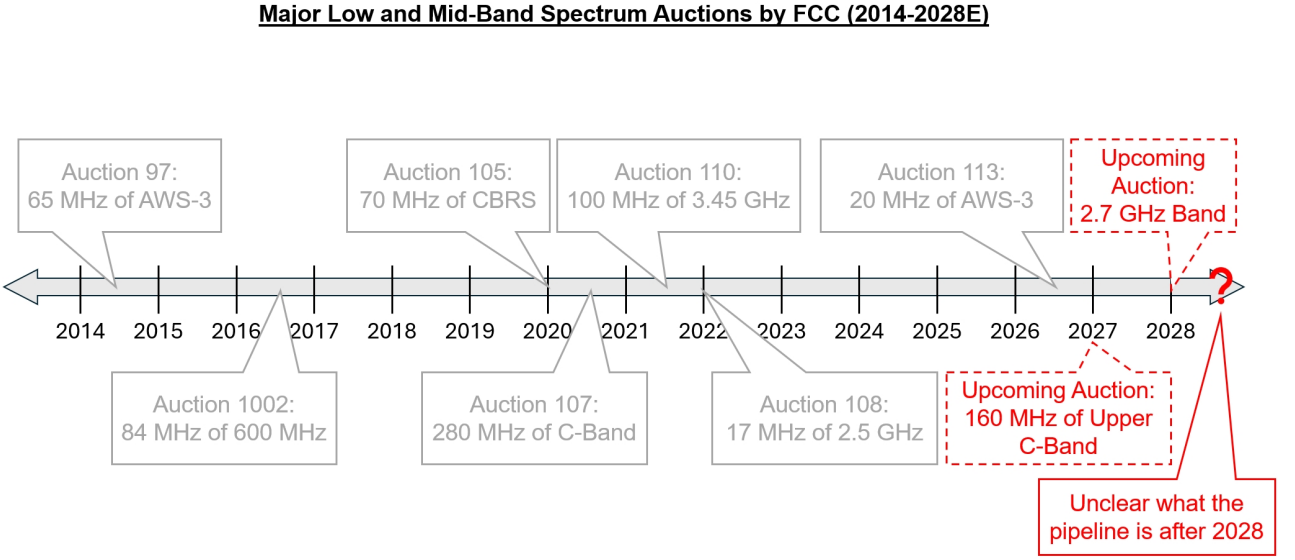
Bloomberg reported on 20 August that it hopes to generate about $6bn — a ~1.7x markup within days of closing. Musk replied "not true." What is confirmed is that FCC Order DA 26-653A1 requires Grain to select a satellite partner through a neutral competitive process, with selection complete by 5 November 2026 and an application filed by 4 December. Note also that the FCC construct is a *secondary satellite license*, which reads more like a long-term lease than an outright assignment — if it is leased, this is a capitalised lease rather than a purchase. AST SpaceMobile is the competing bidder and already holds temporary FCC authority to test on these exact frequencies.

3. Upper C-band — capacity, and a four-year wait.

Auction 115 offers 160 MHz at 3.98-4.14 GHz in eight unpaired 20 MHz blocks across 3,248 licenses, with bidding opening 27 April 2027. This is a capacity layer and nothing else. Its upload reach is roughly 60% of low-band, so a C-band-led coverage build would need far more towers than any scenario here contemplates — we model it strictly as an overlay on steel already erected for coverage. It also cannot be switched on before 31 December 2030 in the top 75 markets, or 1 July 2031 elsewhere, which means whatever SpaceX pays at auction in 2027 sits on the balance sheet for roughly four years. There is no pre-auction aggregation limit; the spectrum screen gets applied case by case afterwards.

The shape of the problem, then: SpaceX has committed to $20bn of spectrum that gives it capacity but not reach, the asset that gives it reach is unsigned and contested, and the asset that gives it real capacity is four years from switch-on.

EXHIBIT 19: **So far the only approved upcoming auctions are for 160 MHz of Upper C-Band (to be used in 2031) and an undetermined amount of the 2.7 GHz band**



Source: Company filings, SNL Kagan, FCC, Bernstein analysis

BENCHMARKING SPECTRUM COSTS

Spectrum is priced per megahertz per person covered — $/MHz-POP — which is the only way to compare bands of different widths across different footprints. Spectrum auctions are notoriously hard to predict - the costs can vary wildly depending on who is bidding, what the alternatives are, the size of the geographic units, and the auction rules themselves. Fun fact: both Madison and Laurent (and another of our Bernstein analysts who won't be named here) have all participated in spectrum auctions. Ask us for our fun game theory stories if you're still poring through this hefty note.

The two spectrum values in question are for the Grain portfolio and for the Upper C-band auction:

- The Grain holdings are an interesting one - Grain paid T-Mobile $2.9B plus $0.3B in licenses - about $0.69/MHz-pop. It was cheap since T-Mobile was required to divest it - Dish had the option initially, extended once in 2024, and Grain eventually

acquired it at ~80% of the Dish strike price. Bloomberg suggested the value at $6B ($1.29/MHz-pop), but it's a somewhat limited buyer set - only AST and potentially SpaceX. We model a range of $4.5-$8.5B implying $0.97-$1.83/MHz-pop.

- Upper C-band is in some ways more normal - it'll have more bidders (all of the incumbents) and some precedent (lower C-band, Auction 107). In theory, this should price lower than Auction 113 (The AWS-3 re-auction from June of this year) netting $2.53/MHz-pop - that was paired spectrum bought by incumbents. It was also immediately deployable. Upper C-band is unpaired, carries ~4 years of clearing wait time, and is capped at 450ft of antenna height. The better comparable is likely Auction 107 from 2021 where pricing was closer to $0.94/MHz-pop. Additionally for that auction, winning licensees pay pro rata into a pool estimated at ~$10B: $6.3B of accelerated relocation initiatives (SES $5.6bn, Eutelsat $504m, Telesat $189m), $4-5bn of estimated cost reimbursement, and open-ended radio-altimeter retrofit rebates. This puts our estimate for Upper C-band at $0.85-$1.25/MHz-pop plus a portion of the $10.3B rebate pool (an effective incremental $0.21/MHz-pop). Our cases have SpaceX winning 20-60MHz, putting total costs at $6.5B-14.2B for Upper C-Band.

Spectrum is 40—70% of the network build cost — $29-58B. This is the most critical debate and sensitivity, but almost impossible to get better precision on.

EXHIBIT 20: **Spectrum Value Comps**

Grain Spectrum Comps	Date	$Bn	$/MHz-POP
Grain T-Mobile Purchase	Aug-2026	$3.20	$0.69
DISH option on the same portfolio (never exercised) (1)	2020-24	$3.59	$0.80
Auction 73 - 700 MHz C block (2)	2008	$4.75	$0.76
Auction 1002 - 600 MHz incentive auction (3)	2017	$19.80	$0.88
Verizon buys UScellular 850 MHz cellular (4)	Oct-2024	$1.00	$1.44
AT&T / EchoStar 600 MHz + 3.45 GHz (5)	Closed Jul-2026	$23.00	$1.40
Auction 73 - 700 MHz B block (6)	2008	$9.14	$2.24
Auction 97 - AWS-3 paired (7)	2015		$2.71

1. $3.59bn / 13.5 MHz / 332m POPs

2. Regional licences, open-access conditions

3. 70 MHz nationwide, weak bidder participation

4. Most recent low-band secondary trade. New Street put the 850-only slice at ~$1.51.

5. Blended. No band split disclosed by AT&T or any analyst.

6. Peak low-band pricing, pre-smartphone land grab

7. Not low band, but the paired-spectrum high-water mark

Source: Bernstein analysis and estimates

EXHIBIT 21: **Spectrum Position Scenario Overview**

Metric	Units	Metro No Grain	Metro Grain	National No Grain	National Grain
Total MHz held	MHz	85	99	105	119
Usable uplink MHz (1)	MHz	**20**	**25**	**20**	**25**

1. This is the binding resource — AWS-4 downlink (2180-2200 MHz) has no matched uplink in the portfolio, as the n66 pair went to Verizon, T-Mobile, and AT&T at Auction 113 (June 2026).
Source: Bernstein analysis and estimates

BUILD UNIT ECONOMICS

Once you've gotten this far, there's no point in getting lazy about unit costs. We price each tower from its parts, which lands between $258k and $364k all-in across our cases. For reference, Dish was $317,600 per site.

HOW WE MODELED IT:

We went line-by-line: radios, antennas, the baseband computing at the base of the tower, cabling, mounting hardware, the tower crew's labor, the power plant, the backhaul connection (when fiber-fed as opposed to satellite backhauled), engineering and zoning work, and project management. Most of these come from the FCC's own catalog of eligible expenses (DA-21-947A4) — compiled when the government was reimbursing carriers for equipment swaps, which makes it an unusually well-documented price list. We also used the CostQuest 5G and 4G cost models and our own network expertise.

For 3-5% of sites, we assume they need a new tower build. We think through the C-band overlay depending on whether crews install it during the original climb or come back later, program overhead of 10-17%, and an allocated share of the core network and IT. We credit Open RAN with no discount per site, because the evidence does not support one: the FCC-commissioned Widelity study found no significant cost advantage, and AT&T attributed its savings to playing vendors against each other on unit pricing rather than to the technology itself. Running costs — tower rent, ground lease, backhaul, power, maintenance — are modeled per site per year, escalated at 2.5-3.0% and discounted over fifteen years at 9%.

We also put in a pace ceiling. The entire US builds only 1,200-2,000 genuinely new towers a year, and about a quarter of those are not even for wireless. We cap new-build additions between 1200 and 1500 per year across scenarios and cap additions to existing towers at 5,000-9,000 a year against DISH's demonstrated peak of about 5,000. Even on those assumptions, the base-case build takes 8.4 years, the no-Grain version takes 12.7, and Premium without Grain takes 8.1 (assuming a much more aggressive push).

While the capex is the more exciting number for this analysis, we also do an Opex build (hey tower friends). Our network Opex ranges are ~$2B-~$78B at full build, which again won't hit for several years.

EXHIBIT 22: **Capital Cost Metrics Scenario Overview**

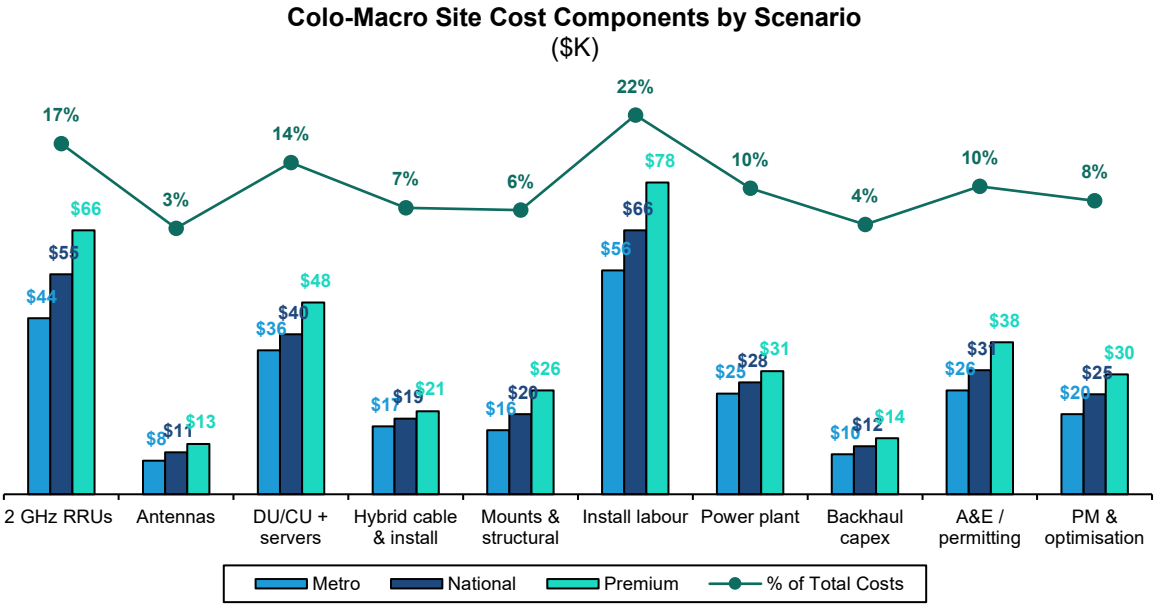
Metric	Units	Metro No Grain	Metro Grain	National No Grain	National Grain
Network CAPEX (excl. spectrum) (1)	$bn	**$21.0**	**$14.3**	**$43.6**	**$29.7**
Capex per macro site (colocation)	$	$258,610	$258,610	$306,400	$306,400
Capex per POP covered	$	$87.75	$59.85	$138.66	$94.35
Marginal CAPEX per incremental POP - coverage step in isolation (2)	$	**-**	**-**	**$79.58**	**$79.58**
Spectrum (EchoStar + Upper C-band all-in)	$bn	**$28.1**	**$32.6**	**$35.8**	**$41.8**
Total Program Cost (3)	$bn	**$49.1**	**$46.9**	**$79.5**	**$71.5**

1. DISH spent $7.9bn ex-spectrum for ~25,000 sites and 80% of POPs.

2. National columns isolate the 70%-to-92% coverage step; Premium isolates 92%-to-95%. Grain is held constant within each comparison, so this is coverage-only.

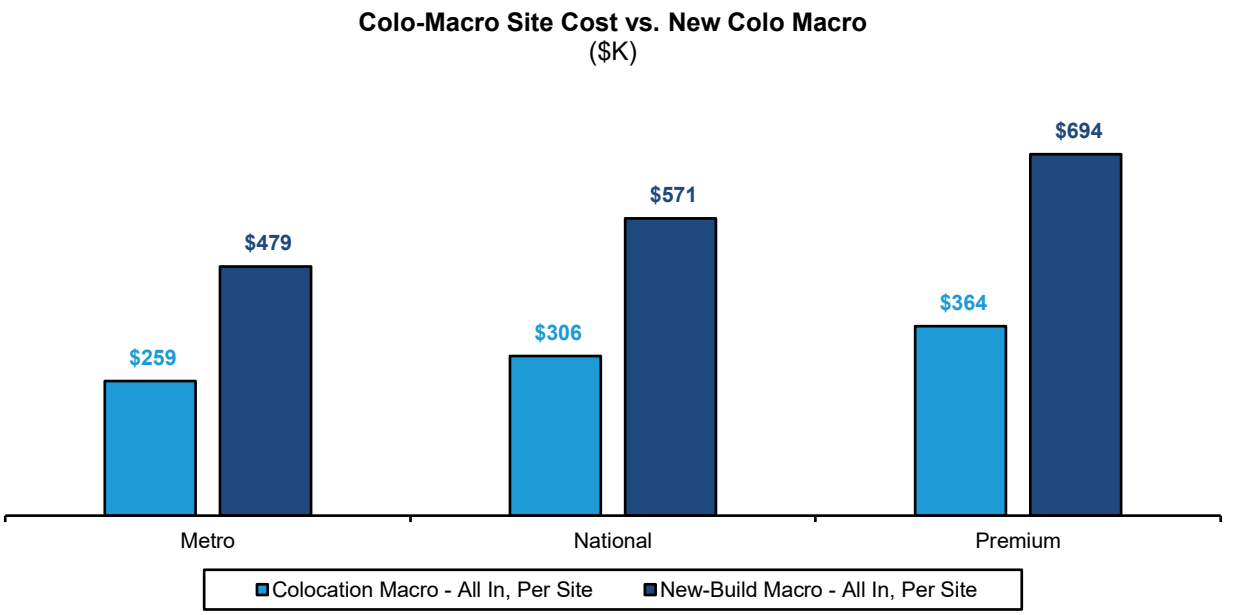
3. Network build plus spectrum — excludes working capital, subscriber acquisition, handset subsidy, retail, and the satellite constellation.
Source: Bernstein analysis and estimates

EXHIBIT 23: **Colo-Macro Site Cost Components by Scenario ($K)**



Costs are the same in Grain/No Grain Scenarios
Source: Bernstein analysis and estimates

EXHIBIT 24: **Colo-Macro Site Cost vs. New Colo Macro ($K)**



Source: Bernstein analysis and estimates

EXHIBIT 25: **Operating Cost Metrics Scenario Overview**

Metric	Units	Metro No Grain	Metro Grain	National No Grain	National Grain
Opex per macro site per year	$	$58,721	$58,735	$57,921	$58,148
Network opex at full build	$bn/yr	**$3.4**	**$2.3**	**$5.7**	**$3.9**
NPV of 15 years of tower lease payments [1]	$bn	$11.1	$7.4	$17.2	$11.4
Total 15-year cash cost (CAPEX + Spectrum + NPV of opex) [2]	$bn	**$81.2**	**$69.0**	**$133.7**	**$108.7**

1. Goes straight to the tower companies. This is the number the Towers monetise.

2. The number to compare against an equity story. For scale: SpaceX's entire disclosed. EchoStar spectrum commitment is ~$21.6bn.
Source: Bernstein analysis and estimates

MODEL VALIDATION

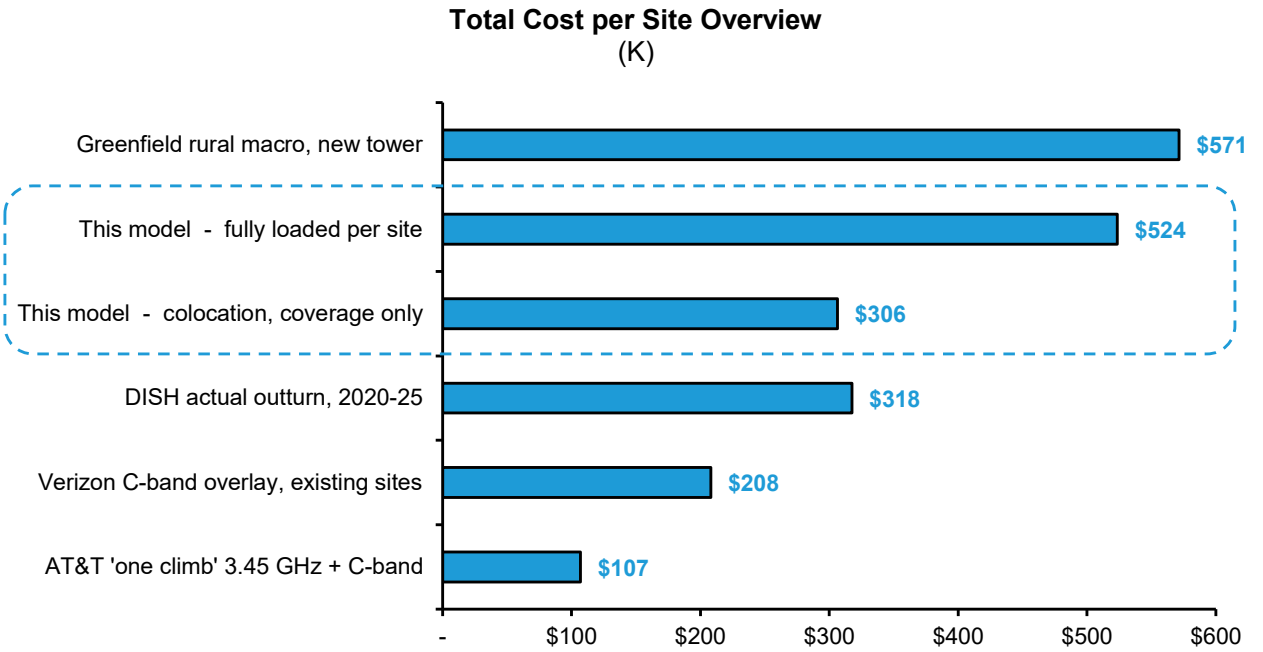
Just to make sure we still have our network engineering chops, we thought we should put this model to a proper test. Give the engine DISH's spectrum and coverage target, and it predicts 22,952 towers against the roughly 25,000 DISH actually built — **8.2% low, so it errs on the conservative side, which is what we'd prefer.**

The DISH comparison runs across the full urban-and-suburban land area rather than any scenario's coverage target, so changing our SpaceX base case cannot quietly improve how well the model appears to match reality. Two further checks: the 600 MHz rerun, which confirms the near-linear frequency relationship inside the model rather than taking it on faith; and a density comparison against a real incumbent, where our base-case build serves 5,386 people per tower against T-Mobile's 4,087, or 0.71x. That is a thinner grid than an incumbent's, exactly as a coverage-first build should be, but it sits in the same league — unlike DISH at roughly 10,700 people per tower, which is the signature of a network built to satisfy a regulator rather than to serve customers.

We stress tested ten of our inputs, each changing one input and recalculating the chain: ask the network to work three decibels deeper inside buildings, or hold the cell edge to a better standard, and the tower count swings 38.5% and the capital bill 35%. By contrast, raise every single unit cost by 25% and the total program moves just 6.4%, because spectrum is roughly two thirds of the base-case bill. The constructed part of our population curve is worth 6.9%.

The practical implication is that this model is meant to be argued with on its own terms. A reader who thinks SpaceX would build to a thinner engineering standard than our National case can and should move those two design inputs and read the answer off the model rather than debating the conclusion.

EXHIBIT 26: **Total Cost per Site Overview**



The model's cost per site against every comparable US benchmark. DISH is the only greenfield build this century; Verizon's C-band program is the cleanest capacity-overlay comparison.
Source: Bernstein analysis and estimates

APPENDIX

EXHIBIT 27: **Model Inputs Overview Part 1**

COMMON RECEIVER & MARGIN TERMS

		Metro No Grain	Metro Grain	National No Grain	National Grain	Premium No Grain	Premium Grain
UE transmit power (Power Class 3)	dBm	23.0	23.0	23.0	23.0	23.0	23.0
UE antenna gain incl. body loss	dBi	(3.0)	(3.0)	(3.0)	(3.0)	(3.0)	(3.0)
UE EIRP	dBm	**20.0**	**20.0**	**20.0**	**20.0**	**20.0**	**20.0**
Thermal noise over cell-edge PUSCH allocation	dBm	(112.42)	(112.42)	(112.42)	(112.42)	(112.42)	(112.42)
gNB receiver noise figure	dB	2.5	2.5	2.5	2.5	2.5	2.5
Receiver noise floor	dBm	(109.92)	(109.92)	(109.92)	(109.92)	(109.92)	(109.92)
Required uplink SINR at cell edge	dB	(4.0)	(4.0)	(3.0)	(3.0)	(1.5)	(1.5)
Receiver sensitivity	dBm	**(113.92)**	**(113.92)**	**(112.92)**	**(112.92)**	**(111.42)**	**(111.42)**
Feeder / jumper loss	dB	0.5	0.5	0.5	0.5	0.5	0.5
Interference margin	dB	2.0	2.0	3.0	3.0	4.0	4.0
Shadow-fade margin	dB	7.0	7.0	7.5	7.5	8.0	8.0
Fixed loss subtotal (feeder + interference + shadow fade)	dB	**9.50**	**9.50**	**11.00**	**11.00**	**12.50**	**12.50**

COVERAGE-LAYER BAND SELECTION - which spectrum actually sets the grid

Grain Band 26 acquired and used as the coverage layer? (1 = yes)	flag	0	1	0	1	0	1
EFFECTIVE coverage-layer uplink centre frequency	GHz	**1.700**	**0.821**	**1.700**	**0.821**	**1.700**	**0.821**
EFFECTIVE coverage-layer panel gain	dBi	**17.5**	**15.0**	**17.5**	**15.0**	**18.0**	**15.0**
Frequency advantage vs the 1.7 GHz AWS-3 uplink	dB	-	6.33	-	6.33	-	6.33
Net link-budget advantage after the lower panel gain	dB	**-**	**3.83**	**-**	**3.83**	**-**	**3.33**

3GPP TR 38.901 PATH-LOSS MODEL PARAMETERS

UE height h_UT	m	1.5	1.5	1.5	1.5	1.5	1.5
RMa average street width W	m	20	20	20	20	20	20
RMa average building height h	m	5	5	5	5	5	5
gNB height - Urban core & dense metro	m	25	25	25	25	25	25
gNB height - Urban & inner suburban	m	30	30	30	30	30	30
gNB height - Outer suburban & small town	m	40	40	40	40	40	40
gNB height - Rural	m	50	50	50	50	50	50
RMa path-loss constant - tier 1	dB	123.18	123.18	123.18	123.18	123.18	123.18
RMa distance slope - tier 1	dB/decade	39.09	39.09	39.09	39.09	39.09	39.09
RMa path-loss constant - tier 2	dB	121.20	121.20	121.20	121.20	121.20	121.20
RMa distance slope - tier 2	dB/decade	38.84	38.84	38.84	38.84	38.84	38.84
RMa path-loss constant - tier 3	dB	118.10	118.10	118.10	118.10	118.10	118.10
RMa distance slope - tier 3	dB/decade	38.45	38.45	38.45	38.45	38.45	38.45
RMa path-loss constant - tier 4	dB	115.70	115.70	115.70	115.70	115.70	115.70
RMa distance slope - tier 4	dB/decade	38.15	38.15	38.15	38.15	38.15	38.15

Source: Bernstein analysis and estimates

EXHIBIT 28: **Model Inputs Overview Part 2**

T1 Urban core & dense metro (>4,965 /sq mi) | 2 GHz coverage layer (n70 uplink 1695-1710 MHz, FDD)

		Metro No Grain	Metro Grain	National No Grain	National Grain	Premium No Grain	Premium Grain
Centre frequency (uplink)	GHz	1.70	0.82	1.70	0.82	1.70	0.82
gNB panel / array gain	dBi	17.5	15.0	17.5	15.0	18.0	15.0
Uplink beamforming / RX combining gain	dB	-	-	2.0	2.0	3.0	3.0
TDD uplink duty-cycle penalty	dB	-	-	-	-	-	-
Design building-penetration loss	dB	13.0	13.0	14.5	14.5	16.0	16.0
Total losses (fixed + penetration + TDD)	dB	22.50	22.50	25.50	25.50	28.50	28.50
MAXIMUM ALLOWABLE PATH LOSS (uplink)	dB	**128.92**	**126.42**	**126.92**	**124.42**	**123.92**	**120.92**
Cell radius (38.901 inversion)	m	683	856	607	761	509	619
Cell radius	km	0.68	0.86	0.61	0.76	0.51	0.62
Link-budget inter-site distance (ISD = sqrt(3) x R)	km	**1.18**	**1.48**	**1.05**	**1.32**	**0.88**	**1.07**
Coverage ISD after practical cap (rarely binds outside rural)	km	1.18	1.48	1.05	1.32	0.88	1.07
Coverage cell area (hex, 0.866 x ISD^2)	km2	1.21	1.90	0.96	1.50	0.67	0.99
Capacity ISD floor	km	2.20	2.20	1.50	1.50	1.10	1.10
Capacity cell area	km2	4.19	4.19	1.95	1.95	1.05	1.05

T2 Urban & inner suburban (1,205-4,965 /sq mi) | 2 GHz coverage layer (n70 uplink 1695-1710 MHz, FDD)

		Metro No Grain	Metro Grain	National No Grain	National Grain	Premium No Grain	Premium Grain
Centre frequency (uplink)	GHz	1.70	0.82	1.70	0.82	1.70	0.82
gNB panel / array gain	dBi	17.5	15.0	17.5	15.0	18.0	15.0
Uplink beamforming / RX combining gain	dB	-	-	2.0	2.0	3.0	3.0
TDD uplink duty-cycle penalty	dB	-	-	-	-	-	-
Design building-penetration loss	dB	10.0	10.0	11.5	11.5	13.0	13.0
Total losses (fixed + penetration + TDD)	dB	19.50	19.50	22.50	22.50	25.50	25.50
MAXIMUM ALLOWABLE PATH LOSS (uplink)	dB	**131.92**	**129.42**	**129.92**	**127.42**	**126.92**	**123.92**
Cell radius (38.901 inversion)	m	1,436	1,802	1,276	1,601	1,068	1,301
Cell radius	km	1.44	1.80	1.28	1.60	1.07	1.30
Link-budget inter-site distance (ISD = sqrt(3) x R)	km	**2.49**	**3.12**	**2.21**	**2.77**	**1.85**	**2.25**
Coverage ISD after practical cap (rarely binds outside rural)	km	2.49	3.12	2.21	2.77	1.85	2.25
Coverage cell area (hex, 0.866 x ISD^2)	km2	5.36	8.44	4.23	6.66	2.96	4.40
Capacity ISD floor	km	4.50	4.50	3.20	3.20	2.50	2.50
Capacity cell area	km2	17.54	17.54	8.87	8.87	5.41	5.41

Source: Bernstein analysis and estimates

EXHIBIT 29: **Model Inputs Overview Part 3**

T3 Outer suburban & small town (~200-1,205 /sq mi) | 2 GHz coverage layer (n70 uplink 1695-1710 MHz, FDD)

		Metro No Grain	Metro Grain	National No Grain	National Grain	Premium No Grain	Premium Grain
Centre frequency (uplink)	GHz	1.70	0.82	1.70	0.82	1.70	0.82
gNB panel / array gain	dBi	17.5	15.0	17.5	15.0	18.0	15.0
Uplink beamforming / RX combining gain	dB	-	-	2.0	2.0	3.0	3.0
TDD uplink duty-cycle penalty	dB	-	-	-	-	-	-
Design building-penetration loss	dB	8.0	8.0	9.0	9.0	10.0	10.0
Total losses (fixed + penetration + TDD)	dB	17.50	17.50	20.00	20.00	22.50	22.50
MAXIMUM ALLOWABLE PATH LOSS (uplink)	dB	**133.92**	**131.42**	**132.42**	**129.92**	**129.92**	**126.92**
Cell radius (38.901 inversion)	m	1,957	2,461	1,789	2,249	1,540	1,880
Cell radius	km	1.96	2.46	1.79	2.25	1.54	1.88
Link-budget inter-site distance (ISD = sqrt(3) x R)	km	**3.39**	**4.26**	**3.10**	**3.90**	**2.67**	**3.26**
Coverage ISD after practical cap (rarely binds outside rural)	km	3.39	4.26	3.10	3.90	2.67	3.26
Coverage cell area (hex, 0.866 x ISD^2)	km2	9.95	15.73	8.31	13.15	6.16	9.18
Capacity ISD floor	km	7.00	7.00	5.00	5.00	4.00	4.00
Capacity cell area	km2	42.43	42.43	21.65	21.65	13.86	13.86

T4 Rural (<200 /sq mi) | 2 GHz coverage layer (n70 uplink 1695-1710 MHz, FDD)

		Metro No Grain	Metro Grain	National No Grain	National Grain	Premium No Grain	Premium Grain
Centre frequency (uplink)	GHz	1.70	0.82	1.70	0.82	1.70	0.82
gNB panel / array gain	dBi	17.5	15.0	17.5	15.0	18.0	15.0
Uplink beamforming / RX combining gain	dB	-	-	2.0	2.0	3.0	3.0
TDD uplink duty-cycle penalty	dB	-	-	-	-	-	-
Design building-penetration loss	dB	5.0	5.0	6.0	6.0	7.0	7.0
Total losses (fixed + penetration + TDD)	dB	14.50	14.50	17.00	17.00	19.50	19.50
MAXIMUM ALLOWABLE PATH LOSS (uplink)	dB	**136.92**	**134.42**	**135.42**	**132.92**	**132.92**	**129.92**
Cell radius (38.901 inversion)	m	2,724	3,431	2,488	3,134	2,140	2,615
Cell radius	km	2.72	3.43	2.49	3.13	2.14	2.62
Link-budget inter-site distance (ISD = sqrt(3) x R)	km	**4.72**	**5.94**	**4.31**	**5.43**	**3.71**	**4.53**
Coverage ISD after practical cap (rarely binds outside rural)	km	4.72	5.94	4.31	5.43	3.71	4.53
Coverage cell area (hex, 0.866 x ISD^2)	km2	19.27	30.59	16.08	25.52	11.89	17.77
Capacity ISD floor	km	12.00	12.00	12.00	12.00	10.00	10.00
Capacity cell area	km2	124.70	124.70	124.70	124.70	86.60	86.60

Source: Bernstein analysis and estimates

EXHIBIT 30: **Model Inputs Overview Part 4**

T1 Urban core & dense metro (>4,965 /sq mi) | Upper C-band capacity layer (3.98-4.14 GHz, TDD, 64T64R)

		Metro No Grain	Metro Grain	National No Grain	National Grain	Premium No Grain	Premium Grain
Centre frequency (uplink)	GHz	4.06	4.06	4.06	4.06	4.06	4.06
gNB panel / array gain	dBi	24.5	24.5	24.5	24.5	24.5	24.5
Uplink beamforming / RX combining gain	dB	6.9	6.9	9.0	9.0	10.0	10.0
TDD uplink duty-cycle penalty	dB	7.0	7.0	7.0	7.0	5.2	5.2
Design building-penetration loss	dB	15.0	15.0	18.5	18.5	22.0	22.0
Total losses (fixed + penetration + TDD)	dB	31.50	31.50	36.50	36.50	39.70	39.70
MAXIMUM ALLOWABLE PATH LOSS (uplink)	dB	**133.82**	**133.82**	**129.92**	**129.92**	**126.22**	**126.22**
Cell radius (38.901 inversion)	m	584	584	464	464	373	373
Cell radius	km	0.58	0.58	0.46	0.46	0.37	0.37
Link-budget inter-site distance (ISD = sqrt(3) x R)	km	**1.01**	**1.01**	**0.80**	**0.80**	**0.65**	**0.65**
Coverage ISD after practical cap (rarely binds outside rural)	km	1.01	1.01	0.80	0.80	0.65	0.65
Coverage cell area (hex, 0.866 x ISD^2)	km2	0.89	0.89	0.56	0.56	0.36	0.36

T2 Urban & inner suburban (1,205-4,965 /sq mi) | Upper C-band capacity layer (3.98-4.14 GHz, TDD, 64T64R)

		Metro No Grain	Metro Grain	National No Grain	National Grain	Premium No Grain	Premium Grain
Centre frequency (uplink)	GHz	4.06	4.06	4.06	4.06	4.06	4.06
gNB panel / array gain	dBi	24.5	24.5	24.5	24.5	24.5	24.5
Uplink beamforming / RX combining gain	dB	6.9	6.9	9.0	9.0	10.0	10.0
TDD uplink duty-cycle penalty	dB	7.0	7.0	7.0	7.0	5.2	5.2
Design building-penetration loss	dB	12.0	12.0	15.5	15.5	19.0	19.0
Total losses (fixed + penetration + TDD)	dB	28.50	28.50	33.50	33.50	36.70	36.70
MAXIMUM ALLOWABLE PATH LOSS (uplink)	dB	**136.82**	**136.82**	**132.92**	**132.92**	**129.22**	**129.22**
Cell radius (38.901 inversion)	m	1,227	1,227	973	973	782	782
Cell radius	km	1.23	1.23	0.97	0.97	0.78	0.78
Link-budget inter-site distance (ISD = sqrt(3) x R)	km	**2.12**	**2.12**	**1.69**	**1.69**	**1.35**	**1.35**
Coverage ISD after practical cap (rarely binds outside rural)	km	2.12	2.12	1.69	1.69	1.35	1.35
Coverage cell area (hex, 0.866 x ISD^2)	km2	3.91	3.91	2.46	2.46	1.59	1.59

Source: Bernstein analysis and estimates

EXHIBIT 31: **Model Inputs Overview Part 5**

T3 Outer suburban & small town (~200-1,205 /sq mi) | Upper C-band capacity layer (3.98-4.14 GHz, TDD, 64T64R)

		Metro No Grain	Metro Grain	National No Grain	National Grain	Premium No Grain	Premium Grain
Centre frequency (uplink)	GHz	4.06	4.06	4.06	4.06	4.06	4.06
gNB panel / array gain	dBi	24.5	24.5	24.5	24.5	24.5	24.5
Uplink beamforming / RX combining gain	dB	6.9	6.9	9.0	9.0	10.0	10.0
TDD uplink duty-cycle penalty	dB	7.0	7.0	7.0	7.0	5.2	5.2
Design building-penetration loss	dB	10.0	10.0	13.0	13.0	16.0	16.0
Total losses (fixed + penetration + TDD)	dB	26.50	26.50	31.00	31.00	33.70	33.70
MAXIMUM ALLOWABLE PATH LOSS (uplink)	dB	**138.82**	**138.82**	**135.42**	**135.42**	**132.22**	**132.22**
Cell radius (38.901 inversion)	m	1,669	1,669	1,361	1,361	1,124	1,124
Cell radius	km	1.67	1.67	1.36	1.36	1.12	1.12
Link-budget inter-site distance (ISD = sqrt(3) x R)	km	**2.89**	**2.89**	**2.36**	**2.36**	**1.95**	**1.95**
Coverage ISD after practical cap (rarely binds outside rural)	km	2.89	2.89	2.36	2.36	1.95	1.95
Coverage cell area (hex, 0.866 x ISD^2)	km2	7.23	7.23	4.81	4.81	3.28	3.28

T4 Rural (<200 /sq mi) | Upper C-band capacity layer (3.98-4.14 GHz, TDD, 64T64R)

		Metro No Grain	Metro Grain	National No Grain	National Grain	Premium No Grain	Premium Grain
Centre frequency (uplink)	GHz	4.06	4.06	4.06	4.06	4.06	4.06
gNB panel / array gain	dBi	24.5	24.5	24.5	24.5	24.5	24.5
Uplink beamforming / RX combining gain	dB	6.9	6.9	9.0	9.0	10.0	10.0
TDD uplink duty-cycle penalty	dB	7.0	7.0	7.0	7.0	5.2	5.2
Design building-penetration loss	dB	7.0	7.0	10.0	10.0	13.0	13.0
Total losses (fixed + penetration + TDD)	dB	23.50	23.50	28.00	28.00	30.70	30.70
MAXIMUM ALLOWABLE PATH LOSS (uplink)	dB	**141.82**	**141.82**	**138.42**	**138.42**	**135.22**	**135.22**
Cell radius (38.901 inversion)	m	2,320	2,320	1,889	1,889	1,557	1,557
Cell radius	km	2.32	2.32	1.89	1.89	1.56	1.56
Link-budget inter-site distance (ISD = sqrt(3) x R)	km	**4.02**	**4.02**	**3.27**	**3.27**	**2.70**	**2.70**
Coverage ISD after practical cap (rarely binds outside rural)	km	4.02	4.02	3.27	3.27	2.70	2.70
Coverage cell area (hex, 0.866 x ISD^2)	km2	13.98	13.98	9.27	9.27	6.30	6.30

Source: Bernstein analysis and estimates

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