STARLINK

carbon neutral
global internet

Elon,

Starlink promises to be an important contribution to humanity. I am writing to amplify that contribution. Whereas Starlink promises global high-speed internet, SpaceX should also ensure that Starlink operates in a 100% carbon neutral manner.

The plan for achieving 100% carbon neutrality:

> *The orbital portion of Starlink is already sustainably powered. To achieve 100% carbon neutrality, ground-based gateways should be solar powered. For situations where on-site solar collection is infeasible, grid-based power may be offset by purchasing residential solar capacity. That capacity is deployed as a rebate to Tesla residential solar.*

For customers, choosing a carbon-neutral Starlink over the competition is a no-brainer. Starlink will do for communications what Tesla has done for transportation. It will show the world once more that sustainable products aren't only good for the planet, but also good for business. There is substantial benefit to Tesla's residential solar business by reducing cost to consumers.

SpaceX and Tesla have already made significant strides towards securing a brighter future for humanity. To further those efforts, I strongly encourage implementation of this plan.

Details follow.

Regards,

Bob Burrough

Starlink: Carbon Neutral Global Internet

How Starlink can help save the planet.

Bob Burrough

Starlink promises the world's first globally-accessible, high-speed wireless network. To fight catastrophic climate change, proposed here is a plan to operate Starlink 100% carbon neutrally.

SpaceX and Tesla are in a unique position to do this. SpaceX, as the provider of the satellite constellation, and Tesla, as the producer of renewable energy, together may replace carbon-intensive wireless networks that carry the majority of the world's communications. Starlink will beat the competition with a network that is faster, more accessible, and fights catastrophic climate change.

Raison d'Être

The most important reason is to create a brighter future for humanity by protecting Earth's environment and making humanity an interplanetary species. No other goal gives as much meaning to our lives as this one.

Environmental Impact of Wireless Networks

In 2017, AT&T expended 15.4 TWh of energy to power their network. With their reported 141.5 million wireless subscribers,[1] that's 108.3 kWh per person. By AT&T's own public reports, virtually none of that energy (significantly less than 1%) came from solar.[2] Since the United States energy grid is comprised of 62.9% carbon-based energy, AT&T alone represents over 7.7 million metric tons of CO_2 pumped into the atmosphere.[3] [4] Of course, there are many carriers other than AT&T. The amount carbon emissions caused by wireless networks globally is staggering.

Building a Wireless Network Powered by Renewable Energy

Since details about the design of the Starlink ground-based gateway are not publicly available, we must estimate their energy consumption. The strategy used is to model low and high power scenarios, then make an educated guess as to where the Starlink gateway resides relative to these two extremes.

Low power consumption scenario: To define the low-power-consumption scenario, we recognize that regional distribution of gateways is denser than that of existing cellular networks. There are

[1] AT&T 2017 Annual Report, Page 26 https://investors.att.com/~/media/Files/A/ATT-IR/financial-reports/annual-reports/2017/complete-2017-annual-report.pdf

[2] AT&T Energy Management https://about.att.com/ecms/dam/csr/issuebriefs/IssueBriefs2018/environment/energy-management.pdf

[3] U.S. Department of Energy Environment Baseline, Volume 1: Greenhouse Gas Emissions from the U.S. Power Sector, Page 40 https://www.energy.gov/sites/prod/files/2017/01/f34/Environment%20Baseline%20Vol.%201--Greenhouse%20Gas%20Emissions%20from%20the%20U.S.%20Power%20Sector.pdf

[4] 15,400,000,000 kWh * 0.5 kg CO_2 / kWh = 7,700,000,000 kg CO_2

approximately 200,000 cell sites in the United States,[5] while the Starlink ground-based gateway application calls for installation of 1 million gateways.[6] Assuming each gateway will service a neighborhood-sized region, we may use existing equipment as a baseline. Wireless transceivers that provide neighborhood-scale Wi-Fi are commercially available, and actively used by (eg) Google to provide free public Wi-Fi in the city of Mountain View, CA. For example, the Ruckus T811-CM is a neighborhood-scale Wi-Fi access point capable of 4x4 MIMO up to 1.7 Gbps to 512 users. The Ruckus T811-CM consumes anywhere from 23 to 93.7 watts depending on configuration and load.[7]

Figure 1 - Ruckus T811-CM Wi-Fi access point can serve 512 users up to 1.7 Gbps. It is used by Google to provide free public Wi-Fi in Mountain View, CA. It consumes up to 93.7 watts of energy.

High power consumption scenario: If we assume that both the orbital and ground-based components of Starlink together are analogous to AT&T's wireless network, we may extrapolate the power consumption of each gateway. First, we predict the distribution of power between the ground and orbital components at 50/50. Since the orbital component is already solar powered, that leaves half of AT&T's 15.4 TWh, or 7.7 TWh attributable to ground-based gateways. With one million ground-based gateways, the energy consumption of each would be 878.4 watts[8]. Admittedly, this is a terribly rough approximation, but helps us understand the scale of our estimate of the power consumption of Starlink ground-based gateways.

Estimated power consumption scenario: With the goal of providing neighborhood-scale wireless at Gigabit+ plus speeds, the Ruckus T811-CM is a reasonable baseline. However, a Starlink gateway isn't just an access point. It's also a Ku band transceiver that functions as the uplink to the satellite. Therefore, we estimate the energy consumption of such a system at 2x the power consumption of the Ruckus T811-CM, or 200 watts.

Next, we figure the solar panel size required to power the equipment. In the continental United States, solar yield per day at any site is between 3.5 to 8 $kWh/m^2/d$. Syracuse, NY is towards the bottom of this range while Las Crucez, NM is near the top.

[5] Top 3 Cell Tower Companies in the U.S. by Chris Naigler https://www.fool.com/investing/2016/10/15/top-3-cell-tower-companies-in-the-us.aspx
[6] APPLICATION FOR BLANKET LICENSED EARTH STATIONS https://fcc.report/IBFS/SES-LIC-INTR2019-00217/1616678.pdf
[7] Ruckus T811-CM Series https://ruckus-www.s3.amazonaws.com/pdf/datasheets/ds-ruckus-t811-cm.pdf
[8] $7.7*10^{12}$ Wh / 1000000 / 365.25 * 24h = 878.4W

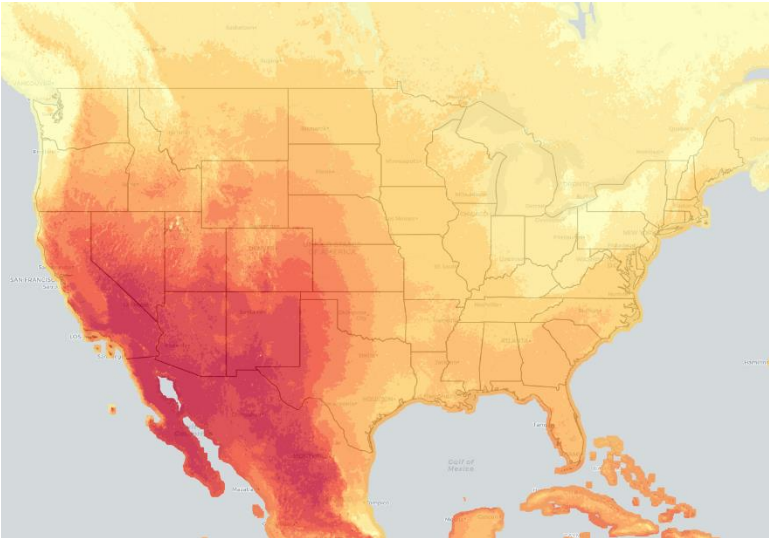

Figure 2 - United States regional solar irradiance, NREL multi-year PSM direct normal irradiance[9]

To evaluate whether deployment of solar for each ground-based gateway is feasible, we figure the worst-case scenario of 3.5 kWh/m²/d. The rationale is simply that if it's feasible to deploy solar in the worst-case, then it is feasible to deploy solar everywhere.

solar potential, worst-case	3,500	Wh/m²
panel efficiency	20%	
net per m²	92	watts
daily yield per m²	700	Wh
charge/discharge efficiency	75%	

Therefore:

Table 1 - estimated power consumption scenarios

scenario	**low**	**high**	**estimate**	
power	100	878	200	watts
daily energy consumption	2,400	21,082	4,800	Wh
charge losses	600	5,270	1,200	Wh
total collection requirement	3,000	26,352	6,000	Wh
collection capacity	393	3,449	785	watts
panel area	4.3	37.6	**8.6**	**m²**
panel width	2.1	6.1	**2.9**	**meters**
battery capacity	2,507	22,031	5,015	Wh

[9] NREL multi-year PSM direct normal irradiance https://maps.nrel.gov/nsrdb-viewer/?aL=chXUF-%255Bv%255D%3Dt%26f69KzE%255Bv%255D%3Dt%26f69KzE%255Bd%255D%3D1&bL=clight&cE=0&lR=0&mC=37.64903402157866%2C-96.15234375&zL=5

Given our estimated 200 watts per gateway, we would need panels with an area of 8.6 m², or 2.9 meters wide where solar yield is least favorable. This is on the order of the area of a typical sedan. So, providing direct solar energy for a 200 watt gateway in the worst case scenario is going to occupy an area less than that of a parking spot. This is utterly reasonable. Everywhere else in the United States, the panel size would be even smaller.

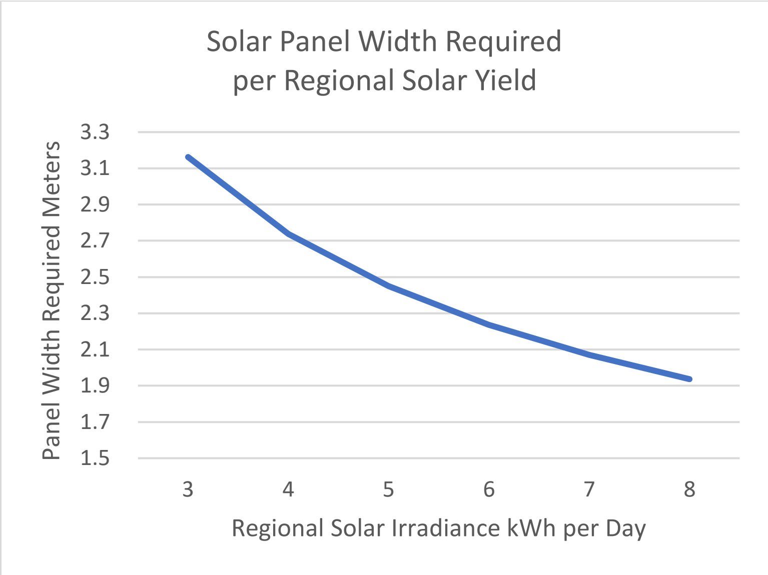

Figure 3 - Solar panel width per regional solar yield

Costs for solar energy collection components:

battery[10]	190	$/kWh
panel rated capacity	200	W/m²
panel[11]	1	$/W/m²
control circuit	100	$/ea

As such, the BOM for the solar collection portion of our 200 watt system in the region with lowest solar irradiance:

Table 2 - solar collection component costs

battery	$ 953
panel	$ 1,714
control circuit	$ 100
total	$ 2,767

[10] Electric Vehicle Battery: Materials, Cost, Lifespan https://www.ucsusa.org/clean-vehicles/electric-vehicles/electric-cars-battery-life-materials-cost#bf-toc-3
[11] Solar Price Survey http://www.ecobusinesslinks.com/surveys/free-solar-panel-price-survey/

As with the physical dimensions, cost is approximately correlated with regional solar yield. These costs are in addition to any costs currently planned for the system which do not relate to renewable energy collection (e.g. transceivers, phased array antennae, amplifiers, network management controllers, provisioning, authentication, etc).

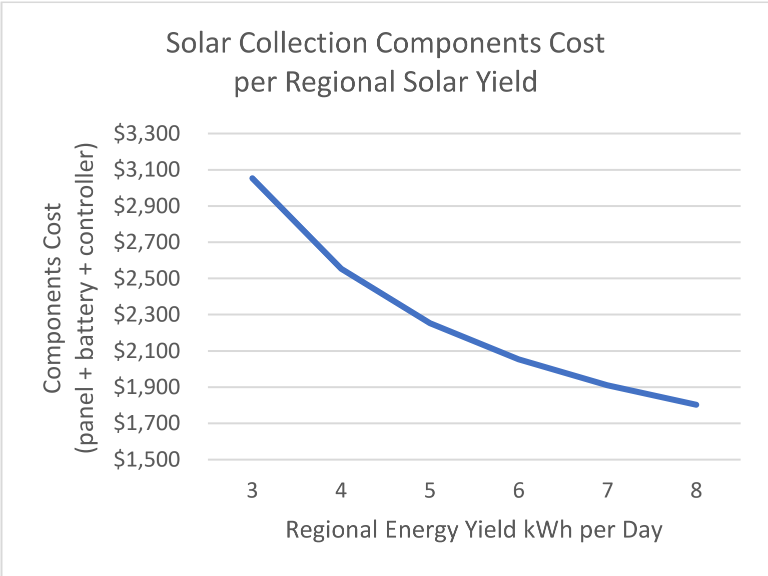

Figure 4 - Solar collection components cost per regional solar yield

We can figure aggregate cost by predicting an average regional solar yield and multiplying the associated cost by 1 million units. If we estimate an average regional solar irradiance of 5 kWh/m²/d, the aggregate cost of solar collection components across the entire system is $2.3 billion. Assuming a lifespan of ten years, the amortized cost is $225.3 million per year (capex).

It is important to understand that nearly the entirety of these costs are paid to Tesla as the vendor of panels, batteries, and controllers. SpaceX gains the benefit of being a good steward of the environment and ingratiating itself to customers as a lifestyle brand, and Tesla gains a committed customer of its renewable energy products. In essence, SpaceX and Tesla would together own this vertical, creating an economy of scale that increases innovation and drives prices down. A virtuous cycle would benefit all products from both Tesla and SpaceX; cars, rockets, satellites, solar panels, batteries, and everything else.

So, what happens when solar production is insufficient? What happens when it's cloudy? How can carbon neutrality be maintained? First, there certainly will be times when sunlight is simply not available. In these situations, the gateway must be powered by the grid. However, there are two critically important aspects of this. First, whereas a gateway may necessarily be powered by the grid, carbon neutrality may be maintained by purchasing residential solar capacity and distributing it in the form of a rebate for Tesla residential solar. Second, the system described above has a battery and a controller. Each gateway may opportunistically recharge itself off the grid when demand for power is lowest and therefore least carbon intensive (i.e. the system may time-shift charge cycles to optimally conform to the Duck Curve[12]). In this way, each gateway may act as grid-attached storage.

Rebates for Residential Solar

One method of offsetting carbon emissions is to purchase solar capacity and deploy it in a manner that supplants the use of carbon-based energy. For example, attaching a solar panel to a home that gets electricity from a coal-fired plant would directly prevent the emission of carbon.

An ideal form for this to take is as a rebate for Tesla residential solar. Basically, an emitter offsets their emissions by helping a family pay for installation of solar panels on their home. A wide range of benefits occurs:

- carbon emissions are neutralized
- residential solar becomes more accessible by being more affordable
- Tesla's residential solar business is energized

To illustrate:

Table 3 - Residential solar rebate annual cost factors

1,000,000	**units**
200	**watts / unit**
8,766	**hours / year**
31.8%	**solar duty cycle**
75%	**charge-discharge efficiency**
2,191,500,000	**kWh / y**
10%	**grid percentage**
62.9%	**grid carbon percentage**
137,845,350	**grid carbon kWh / y**
49,402	**kW capacity**
$1.00	**dollars / watt capacity**
$49,401,544	**capacity cost / year**

In this example, 10% of the network's total energy consumption comes from the grid. Of that, 62.9% or 137.8 GWh comes from carbon-based sources. Assuming a capacity cost per watt of $1, purchasing $49.4 million worth of residential solar and distributing it in the form of rebates will offset carbon emissions for that year. In this way, carbon neutrality of the network is maintained. At an average cost of $85,000 per residential solar installation, Tesla could discount 2,324 installations by 25%. This would dramatically increase interest in Tesla residential solar.

This is a unique opportunity presented to Tesla and SpaceX by virtue of participating in both the renewable energy and consumer broadband markets. Such a vertical integration is not available to any other vendor without astronomical investment. It will be extremely difficult for existing broadband vendors to retroactively provide renewable energy for their networks. Working together, Tesla and SpaceX are in an extremely advantageous position.

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[12] "Duck Curve" https://en.wikipedia.org/wiki/Duck_curve

It's Good for Business

The average cost of grid-based electricity in the United States is 10.27 cents per kWh.[13] The total power consumption of our hypothetical 200 watt system is 6 kWh per day, or 2,191.5 kWh per year. With 1 million gateways, that comes to 2.19 TWh per year. The cost of purchasing that electricity rather than implementing this plan would be $225 million. Eerily, that is almost exactly the $225.3 million dollar amortized cost of building this infrastructure. In essence, you'll be paying the cost of energy anyway, but by putting in the sweat to implement this plan, you're gaining all the commensurate benefits: carbon neutrality, operational expertise, sales, installation, economies of scale to drive solar production lower, innovation, etc.

Implementing this plan puts Tesla in a position to establish an economy of scale with the backing of SpaceX as a committed customer. Raw materials, panel production, transportation, and installation may be purchased in quantities that grant significant discounts. It is highly likely that costs may be strategically driven below those which are cited in this document. Even more importantly, reducing the cost of solar and solar deployment on a broad basis applies not just to this project, but also to Tesla residential solar and other projects as well. For example, it is well-known that Tesla desires to install solar capacity throughout its Supercharger network. Implementing this plan benefits that and every other Tesla and SpaceX effort.

For customers, choosing a carbon-neutral Starlink over the competition is a no-brainer. Starlink will do for communications what Tesla has done for transportation. It will show the world once more that sustainable products aren't only good for the planet, but also good for business. There is substantial benefit to Tesla's residential solar business by reducing cost to consumers.

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About

I am an engineer, inventor, angel investor, and executive producer. I built the most successful products of all time during my career at Apple. I am passionate about technology and driven to give meaning to life by making the world a better place.

Bob Burrough

[13] U.S. Energy Information Administration Electric Power Monthly
https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a