Fiber Broadband Deployment is Paramount To Achieving Zero Carbon Footprint

A CARBON FOOTPRINT ANALYSIS: FTTH VS. HFC/DOCSIS

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Fiber Broadband Association
Sustainability Working Group

Fiber Broadband ASSOCIATION

When fiber leads, the future follows.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The carbon footprint of fiber broadband networks is lower than hybrid fiber coax networks on every sustainability metric, from embodied carbon to carbon in the operational phases, including customer premise equipment (CPE). The FBA's Sustainability Working Group compared the carbon footprint of fiber to the home (FTTH) networks with Hybrid Fiber Coaxial (HFC) data over cable system interface specification (DOCSIS) 4.0 networks. The findings are unequivocal: carbon footprint associated with network component manufacturing (embodied carbon) is 60% less in FTTH networks compared to HFC, installation carbon is 7% less, network operational carbon footprint is up to 96% less, while customer premise equipment is 18% less.

Communications service providers seeking to improve sustainability metrics associated with their broadband deployments will find that overbuilding an HFC plant with fiber will initially cause an incremental increase in carbon footprint — but after converting customers to fiber, the annual reduction in operational carbon will provide a break-even payback in six years. With fiber's ability to scale to nearly unlimited bandwidth speeds, transitioning networks from HFC to fiber provides a far more sustainable option now and for decades to come.

INTRODUCTION

The FBA's Sustainability Working Group studied the environmental impacts of broadband internet services that use the typical Cable Internet approach of HFC, which is defined as fiber to the neighborhood with coaxial cable to the home, versus the higher performance Fiber Broadband Internet approach that uses fiber to the home (FTTH). The specific intent of the working group and this paper was to examine the carbon footprint of HFC vs. FTTH networks in the following life cycle stages:

1. Manufacturing of network infrastructure components and systems,
2. Network infrastructure deployment and buildout,
3. Network operational use (electricity), and
4. Network infrastructure and equipment removal and recycling when existing legacy networks are overbuilt with FTTH.

The HFC Internetworking technology examined is the upcoming CableLabs defined DOCSIS version 4.0 Extended Spectrum DOCSIS (ESD). The FTTH Internetworking technology examined is XGS-PON (10-Gigabit-capable Symmetric Passive Optical Network). Though future PON technologies like 50 Gigabit-capable PON will emerge about the same time as future deployments of DOCSIS 4.0 will begin, the working group chose to examine the current XGS-PON technology as this technology is in volume deployment for FTTH networks and will be used in most cases.

Throughout this paper the terms fiber, FTTH, PON, and XGS-PON will be used to represent fiber broadband internet services. The terms HFC and DOCSIS will be used to represent the typical Cable Internet approach for Cable broadband internet services. It should be noted that Cable Operators have used PON for over two decades, initially for business services, then new build (green field) FTTH, and in some cases cable operators have overbuilt HFC with FTTH. However, in most cases Cable broadband internet services are delivered via HFC and DOCSIS networks as of the date of this publication.

The use of FTTH has been widely embraced by incumbent telecommunications (Telco) broadband internet providers with many overbuilding substantial portions of their existing copper twisted pair telephone network that once used digital subscriber line (DSL) for broadband internet services. Of course, beyond Cable and Telco operators, over 1,100 Fiber Broadband Service Providers have deployed FTTH and PON technology for many years, and these deployments continue to grow rapidly.

The carbon footprint calculations of HFC and Fiber networks are based on current sources; however, continuous improvements are taking place across both ecosystems, thus these findings will continue to evolve. For example, companies in these ecosystems are working to reduce materials, packaging, and power usage, and there will be an increase in the use of recycled materials and renewable electricity sources, all of which will reduce carbon footprint. Some businesses are embracing the concept of a circular economy, where materials are recycled to reduce waste. While a 100% circular economy is impractical with current and near-term technologies, adoption of such philosophies will result in continued reduction of carbon footprint.

OVERVIEW

Fiber deployments are gaining momentum with over 8 billion kilometers of fiber deployed around the world, enough to go back and forth to the sun 27 times [1]. Optical fiber satisfies the bandwidth demand of today and will best satisfy future demand because of its ability to support virtually unlimited symmetric bandwidth. The latest fiber networks for home users can deliver 2,000 times higher bandwidth and over 7 times longer distances for the same number of users vs. ADSL networks, making fiber the best choice [2].

Shutting down legacy DSL copper networks and migrating to all-fiber solutions has become a priority for Telcos, since it enables them to reduce cost and drastically lower yearly carbon emissions while delivering far superior services in terms of broadband speed, latency, and overall reliability. In 2023, altafiber stated that its legacy copper network contributed to 39% of its greenhouse gas emissions, making it a prime target for replacement [3]. When looking at the raw materials and manufacturing of optical fiber and copper, an earlier study calculated that a twisted copper pair used in ADSL networks has a carbon footprint that is 6 times higher than that of an optical fiber of the same length [2].

It should be noted that the cable industry has, for the most part, adopted a "fiber first" strategy for greenfield and expansion builds to deliver more competitive broadband performance, while benefiting from the installation, operational cost and performance advantages of fiber networks. Some cable operators have selected areas to overbuild HFC with FTTH using PON technology with no, or dramatically fewer, active components [powered devices] than HFC networks.

METHODOLOGY

The Greenhouse Gas (GHG) Protocol is a globally recognized standard for measuring and managing greenhouse gas emissions [4]. This document leverages the Life Cycle Assessment (LCA) methodology and calculations methods established by the GHG protocol to compare the carbon footprint of two different networks: an all-fiber network and an equivalent HFC network serving the same number of households. Different life cycle stages are evaluated, from raw material extraction and manufacturing, to network installation and operation, to end-of-life.

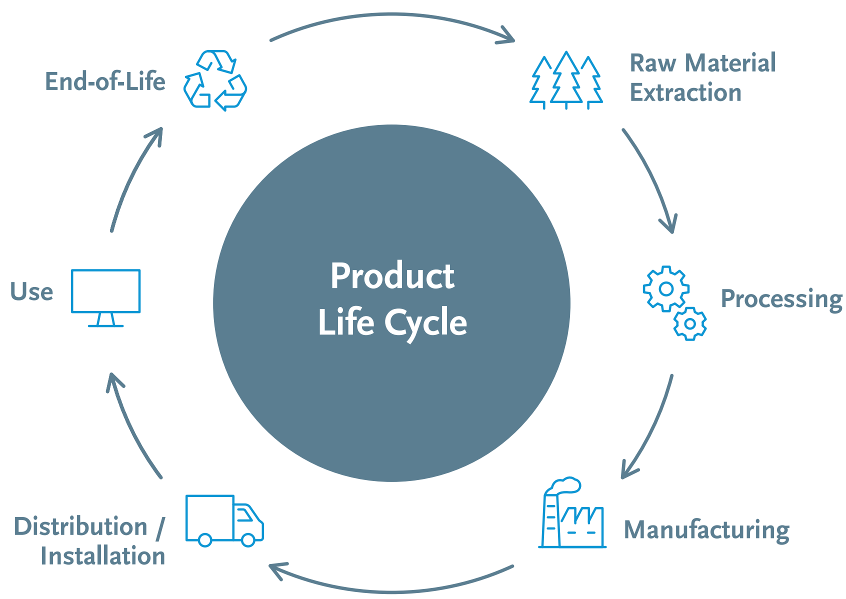


Figure 1: Stages of a Product Life Cycle

For each life cycle stage analyzed, carbon footprint is stated in kgs of carbon dioxide equivalents (CO_2e), and for ease of comparability, is normalized to a per homes passed (HP) and per homes connected (HC) basis.

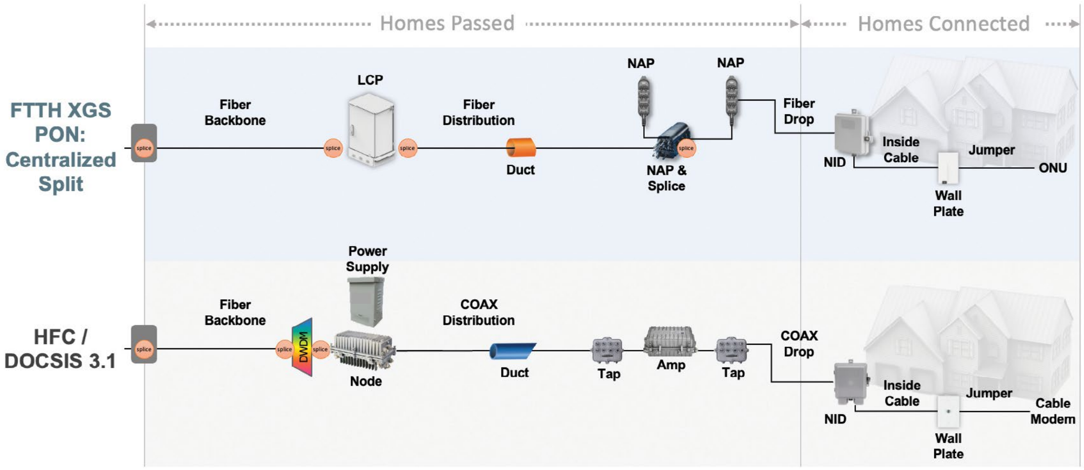


Figure 2: Outside Plant Network Overview

Figure 2 illustrates the outside plant (OSP) network architectures used for this analysis. However as shown further in the paper the data networking systems examine several FTTH XGS-PON and HFC DOCSIS architectures.

The manufacturing of network infrastructure components and systems analysis estimates the carbon footprint of each OSP network based on the amount and types of materials needed to manufacture the components and equipment used in a greenfield deployment that serves an area of 500 suburban homes. A DOCSIS 3.1 architecture was used for the HFC model, as material specifications for DOCSIS 4.0 equipment were not readily available at the time of the committee's work. The network infrastructure deployment and buildout analysis estimates the carbon footprint associated with installation of both networks. The analysis includes the number of installation truck rolls and on-site generator power.

The network operational use analysis examines the electricity used to power networking equipment and estimates carbon footprint on an annual basis. The analysis focuses on the amount of electricity used to power the broadband access network elements and the terminating CPE for both networks.

This paper discusses removing and recycling network infrastructure components, but additional analysis is needed to assess its effects on carbon footprint.

Manufacturing of Network Infrastructure Components and Systems

To estimate the carbon footprint associated with the manufacturing of the different components of the network, three lifecycle stages need to be considered: raw materials extraction, processing, and manufacturing. While there are published Life Cycle Assessments (LCAs that quantify the carbon footprint for certain network components like optical fiber/cable, printed circuit boards (PCBs), and copper/copper cable, LCAs do not exist for the exact components used within these networks. Where LCAs are not available, the average-data method is used. The average-data method calculates carbon emissions based on the mass of a purchased good and an industry average emission factor [5].

Average-data method as defined by the GHG Protocol

CO2e emissions for purchased goods= Σ (mass of purchased good (kg) × emission factor of purchased good per unit of mass (kg CO2ekg/))

Optical fiber's carbon footprint has been calculated through an earlier LCA study. For other elements, most of the mass of network components is composed of common metals, such as aluminum, steel, copper, and/or different types of polymer raw materials. Emission factors used in the analysis are shown in Table 1 [6].

MATERIAL	EMISSION FACTOR	UNIT	SOURCE
Aluminum	8.79	kg CO2e / kg	IPCC AR5 report
Steel	2.63	kg CO2e / kg	IPCC 2013 GWP 100a V1.03
Mixed Metals	5.71	kg CO2e / kg	Average of Steel and Aluminum
Copper	4	kg CO2e / kg	https://sphera.com/2022/xml-data/processes/35a4b3f7-6e52-4e31-9894-e09d72bc0367.xml
Polymer Concrete	0.1480	kg CO2e / kg	www.MaterialsToday.com
Plastic	2.3	kg CO2e / kg	https://v391.ecoquery.ecoinvent.org/Details/LCIA/5485ef2b-55d1-4394-a2b8-5a4fd9e002a4/290c1f85-4cc4-4fa1-b0c8-2cb7f4276dce
Optical Fiber	2.3	kg CO2e / km	https://www.corning.com/media/worldwide/coc/documents/Fiber/white-paper/WP1000.pdf
PCB	18.6	kg CO2e / M2	Life cycle assessment of a printed circuit board manufacturing plant in Turkey (springer.com)

Table 1: Emission Factors Used in Carbon Footprint Calculations

For comparability, the same emissions factors are used for FTTH and HFC networks, with the primary differences being the total mass of the different components contained in the respective networks.

The example calculation below compares one component of the OSP network, the distribution cabling.

	FTTH OSP NETWORK	HFC OSP NETWORK
	ALTOS® Lite Loose Tube, Gel-Free, Single-Jacket, Single-Armored Cable 144 F, Single-mode (OS2)	Coaxial Hardline Cable P3® 750 JCASS SM MT
Length	1 km	1 km
Weight / Length	**247 kg/km**	**399 kg/km**
Optical Fiber	144 km	—
Copper	—	20 kg/km
Plastic	161 kg/km	160 kg/km
Aluminum	—	223 kg/km
Steel	69 kg/km	—
Carbon Footprint	**883 kg CO_2e**	**2,408 kg CO_2e**
Optical Fiber	144 km x 2.3 kg CO_2e/km = 331	—
Copper	—	1 km x 20 kg/km x 4 kg CO_2e/kg = 80
Plastic	1 km x 161 kg/km x 2.3 kg CO_2e/kg = 370	1 km x 160 kg/km x 2.3 kg CO_2e/kg = 368
Aluminum	—	1 km x 223 kg/km x 8.79 kg CO_2e/kg = 1,960
Steel	1 km x 69 kg/km x 2.63 kg CO_2e/kg = 182	—

Table 2: Comparison of Carbon Footprint for 1 km of Distribution Cable (Buried Application) for an FTTH and HFC OSP Network

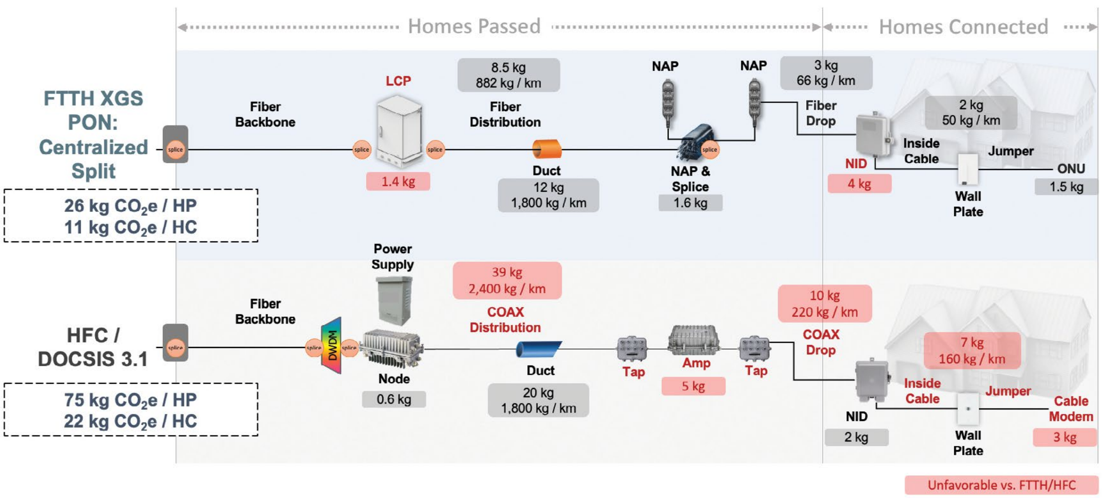
A similar calculation was done for each of the network components and the estimated total carbon footprint for each network is the sum of the carbon footprint of each of the components.

Given the similarities between the Central Office (FTTH) and Head End (HFC) network components, the carbon footprint analysis is centered on the OSP portion of the network.

KEY FINDINGS

According to the analysis, **the carbon footprint associated with manufacturing the components of an all-fiber network is approximately 60% less than that of an equivalent HFC network.**

One primary difference is driven by use of cables in the all-fiber network that are smaller and lighter than those used in an HFC network. The optical fiber cables used for distribution, home connection, and in-resident cabling have on average 60% less carbon footprint than the coax cable used for the same purposes. In the example of the distribution cable above, there are approximately **38% fewer materials needed for every km of optical fiber distribution cable compared to a coaxial hardline distribution cable.**



OSP Network Estimated Embodied Carbon per 1 HP / 1 HC (30% aerial, 70% buried)

Figure 3: Carbon Footprint Associated with Manufacturing of Network Components (Embodied Carbon), Comparison of All-fiber and HFC OSP Network

Fiber benefits from fewer hardware requirements for home connections, unlike HFC networks that need additional active (powered) hardware components in the outside plant to amplify signals for similar distance and speed.

As illustrated in Figure 3, all-fiber OSP networks reduce embodied carbon by 65% for each home passed and by 50% for each home connected (vs HFC networks).

These estimates are likely understated as they do not take into account the energy and electricity used in manufacturing components, or the effects of delivering the final product to the communications service provider. Earlier LCA studies have shown that an increase in material mass correlates with greater energy and electricity consumption during manufacturing. Additionally, as material mass increases, efficiency in transportation decreases, leading to a higher carbon footprint.

Network Infrastructure Deployment and Buildout

The carbon footprint associated with the installation of networks is calculated based on the amount of fuel burned, either diesel or gasoline, and total distance traveled. The amount of fuel burned is estimated based on the number of trips from the garage to the worksite and back, the time engines run on site either in idle or moving during construction, and the use of generators for electricity at work sites.

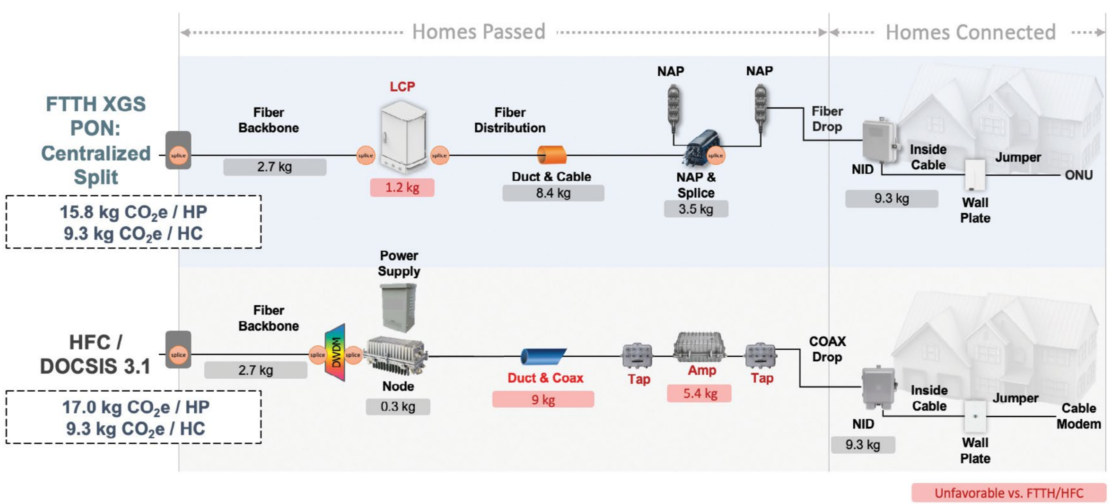
Standard emission factors from a typical passenger vehicle, as defined by EPA, are used and shown below [7].

How much tailpipe carbon dioxide (CO2) is created from burning one gallon of fuel?

- CO2 emissions from a gallon of gasoline: 8,887 grams CO2/gallon
- CO2 emissions from a gallon of diesel: 10,180 grams CO2/gallon

KEY FINDINGS

When determining the carbon footprint on a per-home basis, installation of an all-fiber network is estimated to generate approximately 15.8 kg of CO2e for each home, which is 7% less than the estimated 17kg of CO2e when installing an HFC network. The majority of the carbon footprint in both networks arises from boring and pulling cable, with any additional CO2e from the HFC network attributed to the requirement of additional taps and amplifiers. When looking at homes connected, both all-fiber and HFC have equivalent carbon footprints of about 9 kg CO2e per home connected. For context, the installation carbon footprint for passing a home in either network equates to the emissions from burning approximately 2 gallons of gasoline, with connecting those homes accounting for another gallon's worth of emissions on average.



OSP Network Installation Carbon per 1 HP / 1 HC (30% aerial, 70% buried)

Figure 4: Carbon Footprint Associated with Network Installation, Comparison of All-fiber and HFC OSP Network

Network Operational Use (Electricity)

The electricity used to power networking equipment will continue to generate carbon emissions if non-renewable electricity sources are used. This analysis is based on several models built to examine the electricity consumption and thus operational carbon footprint of networks using FTTH with XGS-PON (10 Gigabit Symmetrical PON) technology and HFC with DOCSIS 4.0 ESD technology. These models examine different deployment architectures that affect power consumption, accounting for both the service provider's access network and the customer-powered CPE. Despite technological differences, their core network functions are similar, allowing a direct comparison of electricity usage and the resulting operational carbon footprint.

The telecom sector recognizes that all-fiber networks consume less power due to fewer powered network devices needed to carry data signals between the provider's facility and the consumer's home. Most broadband service providers using fixed wireline networks have transitioned to fiber to the home for new constructions. Both Telco and Cable providers with existing service areas using copper twisted pair or coaxial cables to the home respectively, known as brownfield, have transitioned some of those legacy networks to fiber to the home, albeit at different rates. Upfront costs make transitioning legacy networks to FTTH a careful consideration decision. This paper is not suggesting the shift to FTTH should be based only on energy savings and carbon footprint reduction. Factors like fiber's superior performance, reliability and durability are also vital. As both Telco and Cable providers use FTTH in both new build and brownfield overbuilds, this paper highlights the carbon footprint benefits of adopting FTTH and PON technologies. This section examines the electricity consumption of FTTH using XGS-PON technology in several system architecture types. These include configurations where the Optical Line Terminal (OLT) is installed in central offices or headend facilities, placed within street cabinets, and integrated into aluminum node housings that are mounted on cables strung between telephone poles or situated on the ground.

Additionally, this section also examines the use of HFC networks using DOCSIS 4.0 ESD technology across different architecture types such as remote PHY device (RPD) attached to a virtual Cable Modem Termination System (vCMTS), as well as the remote MACPHY device (RMD) architecture that functions independently of a vCMTS and its related network equipment.

FTTH Using XGS-PON Technology Electricity Consumption and Carbon Footprint

All use cases assume a 64-way split and the applicable distances are based on current optical technologies, meaning each XGS-PON port could serve up to 64 homes or customers connected. Some providers might opt for a 128-way split, which would shorten the serving area distances, but improve energy efficiency and carbon footprint per homes passed. However, we present data assuming the more typical 64-way split to reflect common practice.

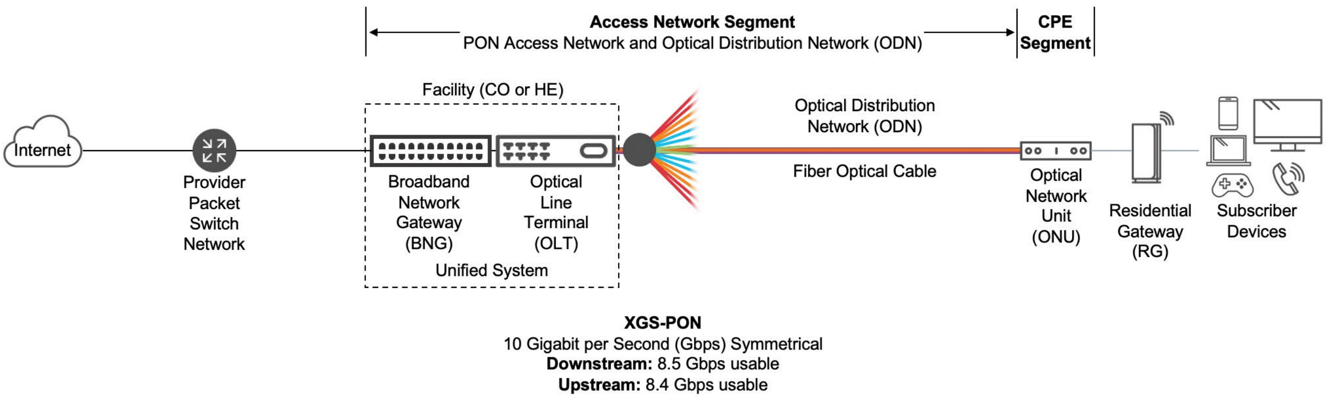


Figure 5: Facility Based OLT and BNG Unified System

As shown in Figure 5, the facility-based OLT assumes a unified system architecture that consolidates Broadband Network Gateway (BNG) as well as OLT functions, and this system architecture does not require any powered network equipment in the outside plant. This assumed an OLT in a temperature-controlled facility using C-temp class E1 double density optics to support a 64-way split at up to 20 kilometers (km) of distance between the OLT and Optical Network Unit (ONU) serving area. This system architecture approach is the lowest power solution for the access network segment.

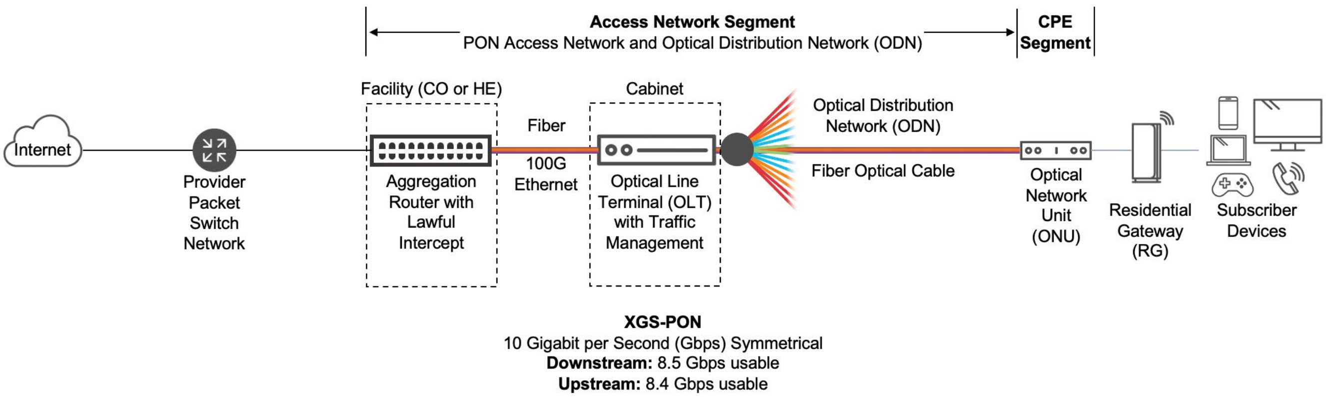


Figure 6: Cabinet Based OLT with Traffic Management Functions

Figure 6 illustrates an OLT in an uncontrolled temperature street cabinet using I-temp class N2 double density optics to support a 64-way split at up to 18.7 km of distance between the OLT and ONU serving area. This assumes a layer 2 OLT that is performing traffic management functions, and an aggregation router that is placed at the facility to connect to the OLT.

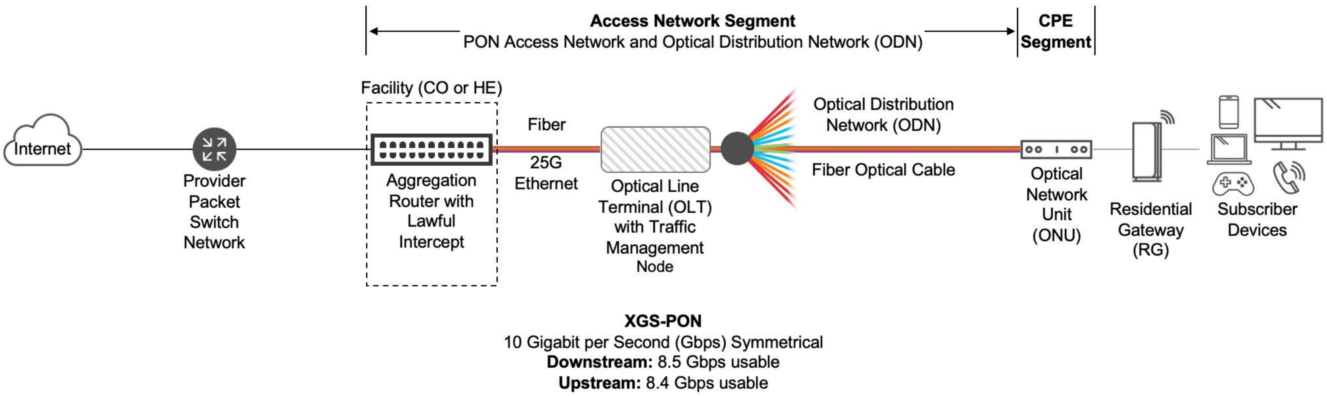


Figure 7: Node Based OLT with Traffic Management Functions

Figure 7 illustrates an OLT in a temperature hardened node housing using I-temp class E1 optics to support a 64-way split at up to 23.2 km of distance between the OLT and ONU serving area. This assumes a layer 2 OLT that is performing traffic management functions, and an aggregation router that is placed at the facility to connect to the OLT.

The FTTH using XGS-PON customer premises equipment segment is the same for all models and had a maximum annual electricity consumption of 105.1 kilowatt hours (kWhs) and an associated annual carbon footprint of 43.84 kilograms of CO_2e.

HFC Using DOCSIS 4.0 ESD Technology Electricity Consumption and Carbon Footprint

The electricity consumption of HFC using DOCSIS 4.0 ESD technology in the system architecture of remote PHY device (RPD) with a virtual CMTS (vCMTS) as well as the required networking components is shown in Figure 8. DOCSIS 4.0 ESD assumes a spectrum band plan ranging from 5 MHz to 1794 MHz, with the upstream occupying 5 to 492 MHz and the downstream ranging from 588 to 1794 MHz, which would have the data capacity to compete with XGS-PON. It is assumed the spectrum is entirely DOCSIS 3.1/4.0 technology and digital video spectrum has been removed to maximize data capacity.

Figure 8 is a high-level illustration of the HFC and DOCSIS networking systems. It shows the access network segment, highlighting the components that contribute to power calculations in the analysis. The illustration is based on an area serving 400 homes passed (HP), with details on OSP network elements like the DOCSIS 4.0 1.8 GHz Remote PHY (RPD) Node, ten 1.8 GHz

Bridger Amplifiers, and fourteen 1.8 GHz Line Extender Amplifiers, drawing from power estimates in a published SCTE 2022 paper [8]. The HFC using DOCSIS 4.0 ESD customer premises equipment segment had a maximum annual electricity consumption of 127.9 kWhs and an annual carbon footprint of 53.33 kilograms of CO2e.

The key findings of the SCTE paper, complemented by our analysis, reveal that energy consumption for HFC and DOCSIS is predominantly attributed to outside plant network elements. Our findings indicate that such elements account for more than 98% of the power consumed by the network's access segment, with the remaining approximately 2% of power allocated to the shared network devices in the access network segment, to include the aggregation router, leaf switch-router, and vCMTS. The remote MACPHY system architecture is also examined but had an insignificant improvement in power consumption and carbon footprint. This is attributed to the high-power usage of the outside plant network equipment, even when data center components are unnecessary, as shown in Table 3.

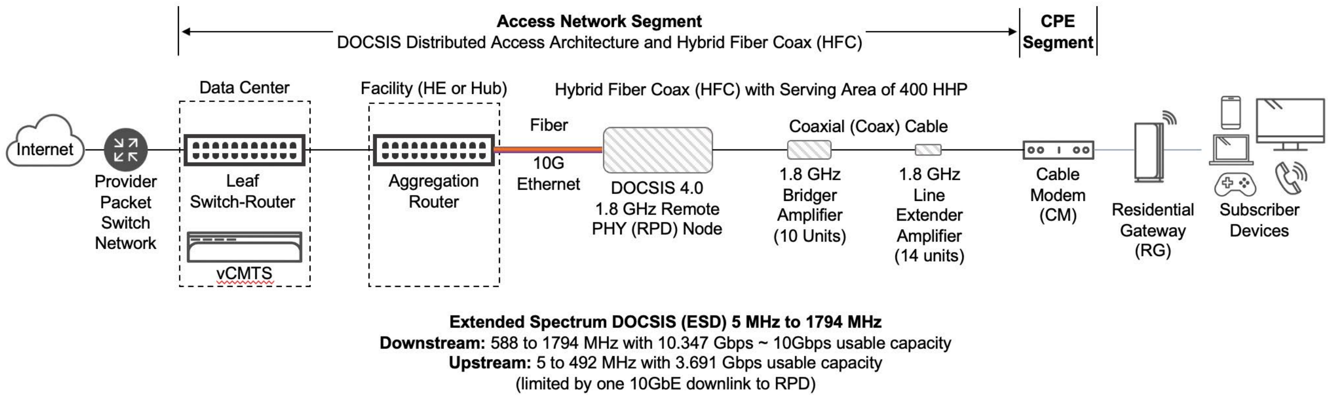


Figure 8: DOCSIS 4.0 ESD Using vCMTS and Remote PHY

The Working Group sourced electricity consumption and capacity data for BNG, OLT, and ONU sourced from Calix, DOCSIS 4.0 1.8 GHz Remote PHY Node and amplifiers sourced from CommScope [8], vCMTS server and chip data from Intel Corporation [9], aggregation router data from Arista Networks [10], leaf switch-router data from Arista Networks [11], and DOCSIS 4.0 ESD cable modem data from Hitron [12].

KEY FINDINGS

A DOCSIS 4.0 HFC access network requires considerably more electricity and therefore results in a higher carbon footprint than a comparable XGS-PON network by any metric, either per homes passed or per subscriber.

FTTH XGS-PON network technology reduces power consumption and operational carbon footprint by 93% to 96% when compared with HFC and DOCSIS 4.0 ESD.

TECHNOLOGY	ACCESS NETWORK SEGMENT	ANNUAL KILOWATT HOURS (KWH)S PER HP	ANNUAL KILOGRAMS CO_2E PER HP	ANNUAL FTTH / XGS-PON DECREASE COMPARED TO HFC / DOCSIS 4.0 RPD
FTTH / XGS-PON	Facility-based OLT with 64 HHP per port	1.01	0.42	96.4%
FTTH / XGS-PON	Cabinet-based OLT with 64 HHP per port	1.19	0.50	95.7%
FTTH / XGS-PON	Node-based OLT with 64 HHP per port	2.00	0.83	92.8%
HFC / DOCSIS 4.0	Remote PHY and vCMTS	27.66	11.53	—
HFC / DOCSIS 4.0	Remote MACPHY Device (RMD)	27.29	11.38	—

Table 3: FTTH / XGS-PON vs. HFC / DOCSIS 4.0 Extended Spectrum DOCSIS

Although less pronounced, fiber technology also offers significant carbon footprint savings over HFC at the customer's premises. A typical XGS-PON ONT is responsible for 43.84 kilograms of CO_2e annually, in contrast to 53.33 kilograms from a DOCSIS 4.0 cable modem, resulting in a 17.8% decrease in carbon footprint for the XGS-PON ONT.

HFC and DOCSIS systems have high electricity consumption due to outside plant network components, including the DOCSIS RPD node and amplifiers. FTTH and XGS-PON have no outside plant powered network elements or use minimal power when cabinet or node based OLTs are placed in the outside plant, serving a wide area of customers.

Network Infrastructure and Equipment Removal and Recycling

As legacy networks become obsolete, they may be overbuilt with fiber to the home infrastructure. Throughout a network's lifecycle, there are mainly two opportunities for recycling cable and equipment.

First, when replacing copper or coaxial networks with fiber, the legacy cabling and equipment can be recovered and recycled. With heightened demand for copper from sectors including electric vehicles, reclaiming these resources becomes economically viable.

Second, the unique composition of optical fiber cables, which include silica glass, polyethylene, and various metals, represents both a challenge and a potential for new recycling technologies. Although traditional recycling plants struggle with the complexity of separating these materials, there are specialized facilities that can do it, through a higher cost compared to common landfill methods. Innovative approaches, such as incorporating fiber in asphalt production and new chemical recycling technologies, are emerging with potential benefits. Overcoming current barriers, such as volume requirements for economically viable recycling processes, could be addressed through collaborative waste consolidation amongst manufacturers and customers. Moreover, future electronics may embrace full lifecycle processing, wherein end-of-life equipment returns to manufacturers for component breakdown and reuse, fostering a circular economy within the industry.

SUMMARY: FIBER IS MORE SUSTAINABLE

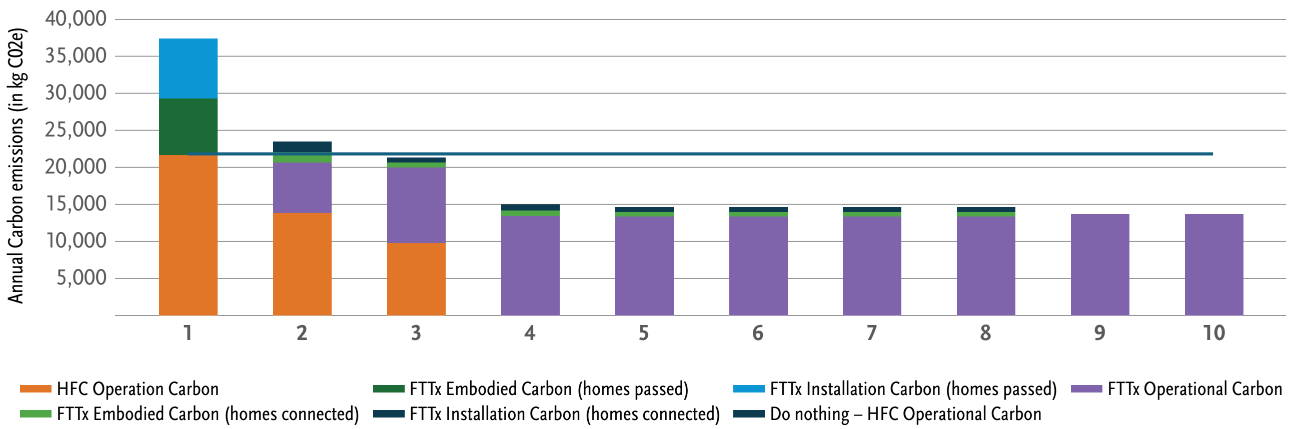
Fiber networks offer significant carbon footprint advantages over HFC networks, from manufacturing of the components, through installation and operation of the network. In the manufacturing of its components, an **FTTH PON network reduces carbon footprint by 60%** compared to an HFC network, due to lighter cables and fewer active network components. The carbon footprint associated with **installation of a fiber network is 7% less than in an HFC network.**

Operationally, an **FTTH XGS PON network reduces carbon footprint by 93% to 96%** versus a comparable DOCSIS 4.0 HFC network, through the elimination or reduction of field powered devices. At the customer premises, an **FTTH ONT cable modem reduces carbon footprint by 18%** versus a DOCSIS 4.0 cable modem. Overall, this analysis demonstrates that a fiber network is the more sustainable choice for broadband infrastructure deployment than a DOCSIS network.

To evaluate the Carbon Footprint, Return On Investment (ROI) of an HFC to FTTH conversion, consider an FTTH overbuild and 4-year conversion of 500 homes passed (300 homes connected, assuming 60% take rates) HFC network vs. a "Do Nothing" scenario where we continue to operate the HFC network for another 10 years.

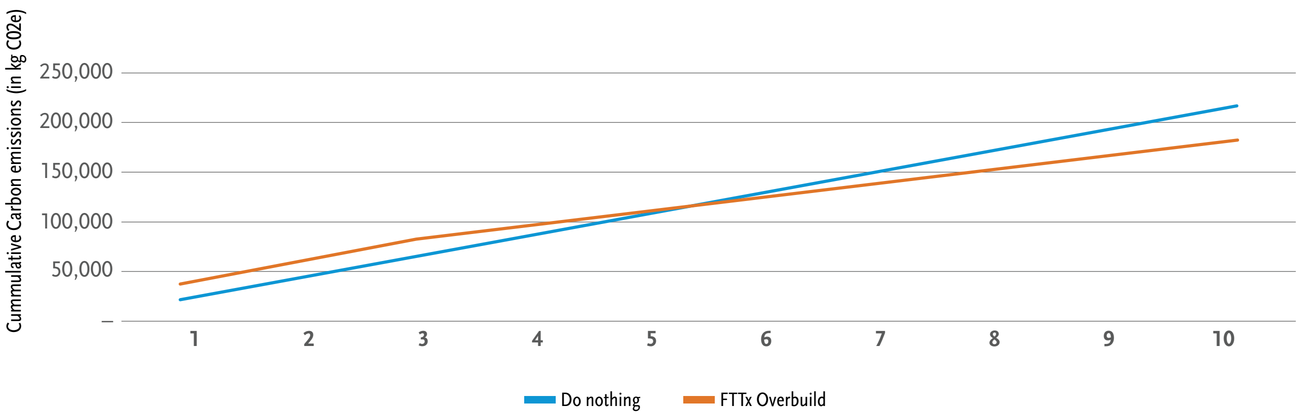
The one-time investment to overlay fiber results in an incremental carbon footprint for Year 1.

- This incremental carbon footprint comes from the manufacturing and installation of new components necessary to pass 500 homes.
- It is projected to take a span of three years to transition all 300 HFC subscribers over to the fiber network.
- In order to factor in subscriber turnover, the embodied carbon involved with installing new drops and ONTs accounts for the remaining 40% of addressable customers at a conservative estimate churn rate of 10% annually.
- By the end of the third year, the conversion of all 500 customers is anticipated to be completed, and within the subsequent four years all 500 homes have drops and ONTs placed because of churn.
- At the conclusion of the third year, the assumption is to shut down the HFC network, whereby only the operational carbon footprint persists. This simple analysis excludes any carbon footprint associated with maintenance truck rolls for either network types.
- In year 6, total carbon footprint of the "Do Nothing" scenario is expected to surpass those from the FTTH overbuild, positioning fiber as the definitive choice for long-term sustainability.



FTTx conversion vs HFC carbon contribution over 10 years
500 Homes Passed and connected but only 300 active subscribers

Figure 9: Annual Carbon Footprint of "Do Nothing" Scenario vs. FTTH Overbuild



FTTx conversion vs HFC cumulative carbon contribution over 10 years
500 Homes Passed and connected but only 300 active subscribers

Figure 10: Total (Cumulative) Carbon Footprint of HFC Network vs. FTTH Overbuild

Further improvements in optical and other electronic technologies are expected to reduce carbon footprint as more power-efficient, higher-bandwidth technologies emerge both at the head end and the customer premises. However, deploying DOCSIS 4.0 networks will likely require additional active components and the truck rolls to install them for future speed increases, resulting in higher carbon footprint.

Efficient recycling of fiber cabling is still relatively new and requires further development to become cost effective at scale. Manufacturers are exploring the recycling of electronics and cable throughout the fiber network, aiming for a circular economy where old components feed new production. The greatest endorsements of fiber as a sustainable broadband solution come from service providers who are either making fiber deployment a priority to meet sustainability goals by retiring legacy copper networks and thereby reducing their carbon footprint, or using fiber as the go-to solution for greenfield construction in new markets and expansion into markets adjacent to existing operations.

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