A sustainable future with optical fiber

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Introduction

Optical fiber is at the heart of our modern connected world, transmitting massive amounts of data daily. Today's connections are made possible by beams of light propagating through hair-thin strands of optical fiber, each potentially capable of supporting more than 150 terabits of data per second.

Invented more than 50 years ago, fiber has undergone numerous evolutions: from connecting disparate locations with long, straight cable runs; to highly interconnected networks connecting over 400M homes [1] with video, telephony, and data; to high-data-rate meshed networks within data centers delivering cloud services to homes and businesses.

For the initial twenty years, optical fiber deployments were primarily in long-haul systems, with the emphasis on maximizing capacity. As fiber penetration increased in access and fiber to the home applications, the focus also shifted to lowering the transmission cost (per bit) in these networks. With the current data rate explosion in data center applications, managing energy consumption and developing sustainable solutions are becoming paramount considerations in optical fiber network expansions, a trend that is likely to accelerate in the near future.

With the escalating demands for bandwidth and data rate transmissions, electrical systems are being replaced by optical systems at an increased pace for a growing number of applications. From a techno-economic perspective, this transition has occurred in different systems at data rate * distance threshold of about 100 Gb/s * m (Figure 1).

Because of the long application distances, the shift from electrical to optical systems for submarine, long-haul, and metro networks occurred in the early days of optcal fiber. The product of data rate and distance is now approaching this threshold even for short distance applications due to rapidly increasing data rate transmissions. As a result, electrical systems are converting to optical systems in access networks, data centers and data center interconnects, fiber to the server, and onboard optics.

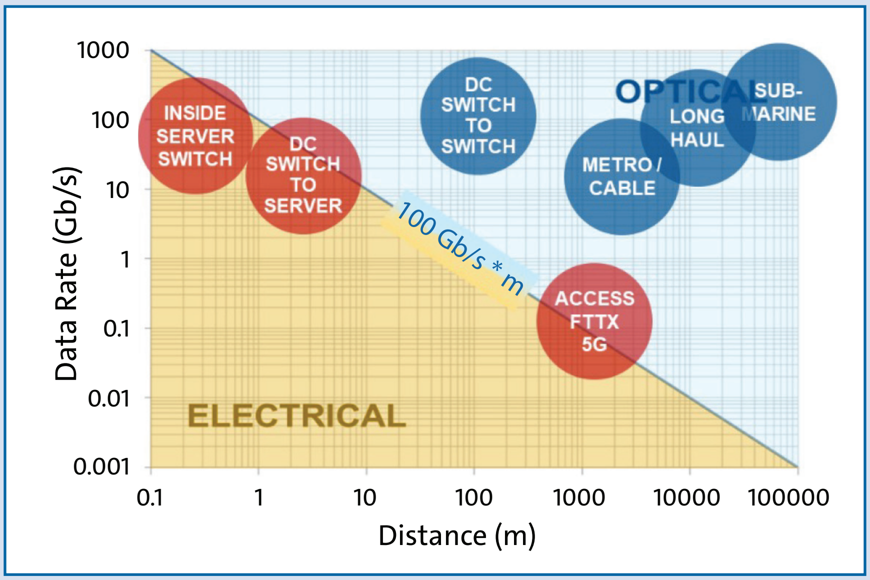

Figure 1. Corning research indicates that as data rates increase, more electrical systems are moving to optical systems

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Fiber is integral to some of the technological advances that are driving the future. AI and machine learning techniques, the engine of data driven decision making, use fiber optic meshed networks to connect massive amounts of data to processing machines at high speeds. The rise of remote working, video conferencing, and the ability to connect to any customer, colleague, or family member anywhere in the world, while on the move, is enabled by a worldwide network of fiber optic cables.

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Expanding the bandwidth of human potential

Since its invention, the world has deployed over 6 billion kilometers of fiber, enough to travel to the sun and back about 20 times. But still, the digital divide persists, with only 23% of the world able to access the internet through a home fiber connection as of December 2021 [1].

For those with access to broadband connectivity, high-speed digital services provide daily benefits. But those unconnected experience a different reality, and inequalities are evident in meeting basic needs such as protection, education, and health. In 2020, the United Nations stated that reliable mobile and internet connectivity is a fundamental human right, enabling citizens in the world to be agents in their own progress, with dignity and self-reliance [2].

The linkage between connectivity and economic growth is also well established. RTI International, an independent nonprofit research institute, estimates that the impact of 2Africa, one of the largest subsea cable projects in the world, will likely be an increase of 0.42 to 0.58 percent in African GDP within the first two or three years of going live [3]. According to the Fiber Broadband Association (FBA), cities with broadly deployed fiber have had 64% higher economic growth than cities without fiber [4].

Sustainability considerations for communications technology

As demand for bandwidth continues to grow and the need for connectivity becomes more critical, developing sustainable solutions becomes a focal point. A deeper focus on how society is impacted, how environmental resources are used, and how costs of development are mitigated is imperative.

In addition to enabling massive bandwidth, optical fiber networks offer environmental benefits over traditional telecommunications networks that use copper. Low energy consumption, low maintenance, and future readiness are amongst the most evident advantages, and have been quantified extensively. Less often talked about is the embodied carbon of optical fiber. Corning quantified this additional advantage through a life cycle assessment (LCA), detailed later in this paper.

Overall, fiber has the potential to meet the present need for pervasive connectivity while minimizing environmental impact, providing sustainable solutions for future generations.

Efficiency and power consumption

A recurring theme in sustainable policy making and strategy planning is the environmental impact of human activities where energy consumption is often at the center of attention. According to a white paper by IDATE [5], the information and communications technology (ICT) sector contributes about 2% of greenhouse gas (GHG) emissions, which comes mainly from energy used for connected devices, data centers, and networks. With rapid digitalization, this figure is expected to increase unless efforts are taken to improve efficiency.

Optical fiber intrinsically provides opportunities to reduce the environmental impact of the ICT sector. Optical fiber supports higher data transmission rates and achieves lower energy consumption in telecommunication networks compared to copper. In transoceanic networks, for example, optical submarine cables replaced copper alternatives in the 1990's. Corning's research of public data indicates that transoceanic capacity accelerated scaling to approximately 35% per year (from 25% per year in the era of copper cables) while maintaining a steady 20% per year reduction in energy per bit. In access networks, optical fiber reduces power consumption by up to 54% depending on the network type (e.g., 4G and 5G) when compared to copper, according to a 2022 study from the Politecnico di Milano [6]. Given these findings, operators in countries like Spain have decided to close entire copper networks and replace them with fiber.

Moreover, driven by its high data capacity, optical fiber networks have a wider service area. According to an FBA study [7], optical fiber can deliver gigabit services without additional active components such as amplifiers over 10 times farther than those associated with copper-based networks.

Resilience

Optical fiber networks require less equipment, resulting in reduced environmental impacts and operational costs. Consequently, optical fiber systems have fewer failure points, lower maintenance requirements, and a reduced need for maintaining active power components, battery replacements, and recurring inspections. Together with more efficient power consumption, these benefits make optical fiber systems more robust than traditional copper networks.

Furthermore, optical fiber does not corrode like metals do, resulting in networks that can last for more than thirty years [8]. According to a Tier 1 North America carrier, "one of the most important benefits of a fiber network is the remarkably long lifespan of optical cables. Case in point: We are running modern, coherent transmission systems over portions of our metro and long-haul networks that were installed prior to 1986, with excellent results."

With fewer failure points, modern optical fiber with higher energy efficiency also has the potential to overcome the bandwidth limitations of existing networks. Energy, healthcare, and other critical infrastructures are becoming more digitized and rely on high performance and high reliability networks. Innovations in optical fiber network development can achieve this through a simplified network architecture.

Fiber is the solution for pervasive connectivity that not only provides high performance but also contributes to achieving sustainable development.

Embodied carbon

Lower operational costs, reduced environmental impacts during service, and resilient transmission of information are possible with optical fiber networks. They have shaped our modern world and have the potential to enable greener digitalization by providing more bandwidth with less material.

The embodied carbon associated with raw material extraction, manufacturing, transportation, and End-of-Life of network infrastructure is a critical element of comparing the environmental impact of competing digital technologies. Corning executed an LCA of the materials contained in optical fiber and its manufacturing process to assess its environmental impact, quantified as carbon footprint (CF). The results from this study were compared to the CF of copper based on publicly available data.

Although different configurations will vary the transmission capacity of a network, we can simplify the analysis by comparing one optical fiber to one copper pair. Consider a twisted copper pair used in Asynchronous Digital Subscriber Line (ADSL) and one optical fiber in an access network. Corning calculated the carbon footprint of one optical fiber to be 2.3 kg CO_2eq/km [9], while two 0.5 mm copper wires [10] are estimated to have a carbon footprint of 14 kg CO_2eq/km [11], 6 times the carbon footprint of fiber over the same length. The latest fiber networks for home users, however, can deliver 2,000 times higher bandwidth over 7 times longer distances for the same number of users.

	Twisted copper pair (0.5 mm dia x 2 wires)	Optical fiber	Comparison Fiber vs. copper
Carbon footprint (kg CO_2eg/km)	14	2.3	6x less
Total distance reach (km)	3	21	7x more
Total Transmission capacity (Mbit/sec)	10	20,000	2,000x more

Figure 2. Cradle-to-gate comparison of twisted copper pair used in ADSL and optical fiber in access network

Based on these values, it is estimated that to achieve the same transmission capacity, over the same reach, the twisted copper pair has a carbon footprint up to 85,000 times higher than that of an optical fiber.

While this analysis is non exhaustive and excludes recycling and disposal as well as other materials and equipment needed to make both cables and operate both networks, it conservatively elevates optical fiber networks over copper from an embodied carbon perspective. This complements the findings of other studies that have confirmed that environmental and economic benefits can be achieved with optical fiber by eliminating active components and simplifying network architecture. Ultimately, studying the embodied carbon that results from the materials and manufacturing of optical fiber helps Corning further improve its environmental performance.

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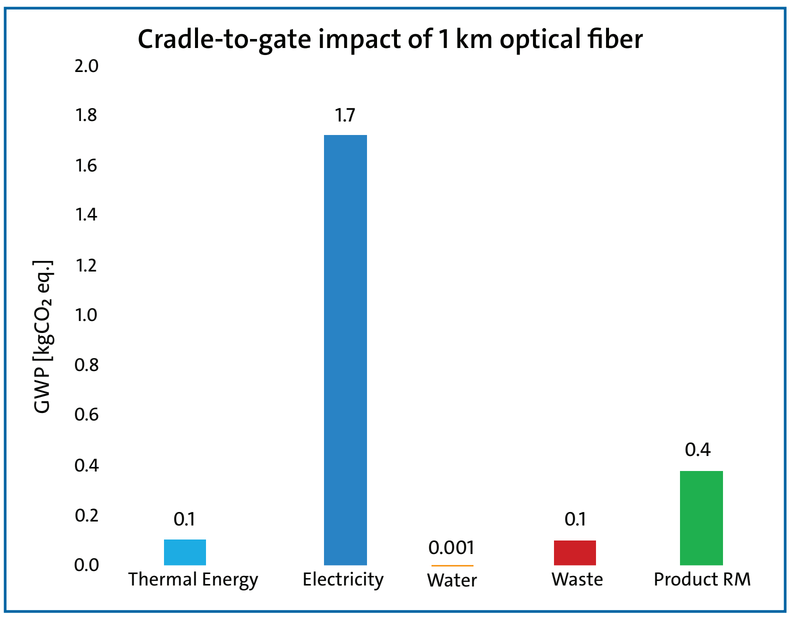


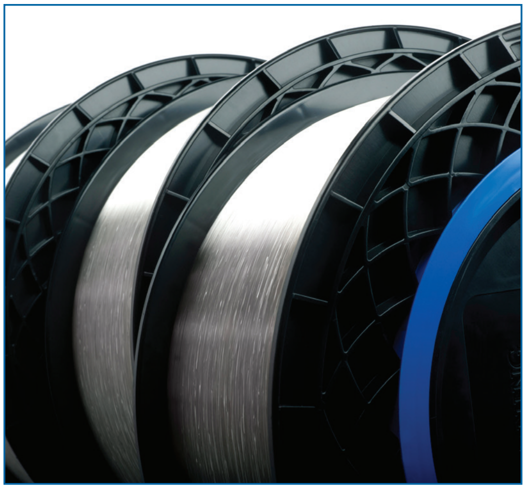
Figure 3. Cradle-to-gate impact of 1 km optical fiber with 242 µm coating diameter

Corning's Cradle-to-Gate LCA study

An LCA is a standard methodology used to quantify the potential environmental impacts of a product or process. It is performed by calculating the GHG emissions associated with the entire life cycle of the product. A commonly used metric that results from an LCA is the global warming potential (GWP), also known as CF. To estimate the CF of optical fiber, all substances needed upstream for its production are considered, as well as electricity and other utilities in what is called a Cradle-to-Gate analysis. This considers all the resources needed and emissions caused by raw material extraction ("cradle"), their processing into semi-finished products, and final manufacturing into optical fiber that is ready for further distribution ("gate").

Corning collected primary data from its production sites and detailed material information to quantify the Cradle-to-Gate impact of its optical fiber and optical fiber cables. Using the calculation method Environmental Footprint 3.0 (EF3.0) and according to the principles and requirements of ISO 14040 and 14044 standards, Corning's LCA study confirmed that the electricity required to manufacture optical fiber is the main source of impact, contributing 70-80% to the overall CF. The study also estimates the raw material impact to be 15-20% of the overall CF [9].

A Cradle-to-Grave analysis was also carried out to understand the impacts of the entire life cycle. This analysis expands the boundaries to consider distribution and End-of-Life, where recyclability and other concepts of circularity play a key role. The Cradle-to-Grave analysis also confirmed that electricity and raw materials in the manufacturing stage are the main hotspots.



How optical fiber is made

To adequately quantify the CF of optical fiber, it is important to understand how it is manufactured. While there are many techniques for making optical fiber, Corning invented and uses the outside vapor deposition (OVD) process. Soot preforms are formed layer-by-layer by deposition of particles on a rotating cylindrical target rod by traversing the soot-laden flame along the axis of the cylindrical target. The soot preforms are sintered to glass and then drawn to optical fibers by treating them at temperatures as high as 2000° C. During the drawing of the optical fibers, the fibers are coated with acrylate coatings and UV-cured to protect the glass fiber from damage and mitigate attenuation increase under external forces.

Due to the elevated temperatures involved in laydown deposition, sintering, and drawing processes, optical fiber manufacturing is energy intensive. As the market leader with the most widely deployed brand of fiber, Corning continues to invest in world class manufacturing technology that drives the highest scale and efficiency. In 2018, Corning hit a significant milestone, achieving a 50% energy intensity reduction in optical fiber and cable manufacturing since 2006, and continues to work on improving it further.

Raw material impact

Corning requires highly pure raw materials to produce low attenuation (low loss) optical fibers. These include silica or doped silica glass, protective acrylate coatings, and other auxiliaries. Results from Corning's LCA study indicate that raw materials contribute between 15% to 20% of the total CF of optical fiber [9], with 50% of this impact attributed to the silica glass precursor used in the chemical vapor deposition process and 40% attributed to the acrylate coating. In general, for an optical fiber with smaller coating diameter, less coating material is needed, resulting in a lower CF of the fiber. In fact, the LCA confirmed that the raw material CF of a 125 µm glass diameter and 190 µm in coating diameter fiber is 17% less than the raw material CF of the standard 242 µm coating diameter fiber with similar glass diameter. This represents a 3% reduction in overall CF between the two fiber types. As industry trends continue to drive towards increased density, reduced coating diameter fibers result in a favorable impact in both fiber and cable CF.

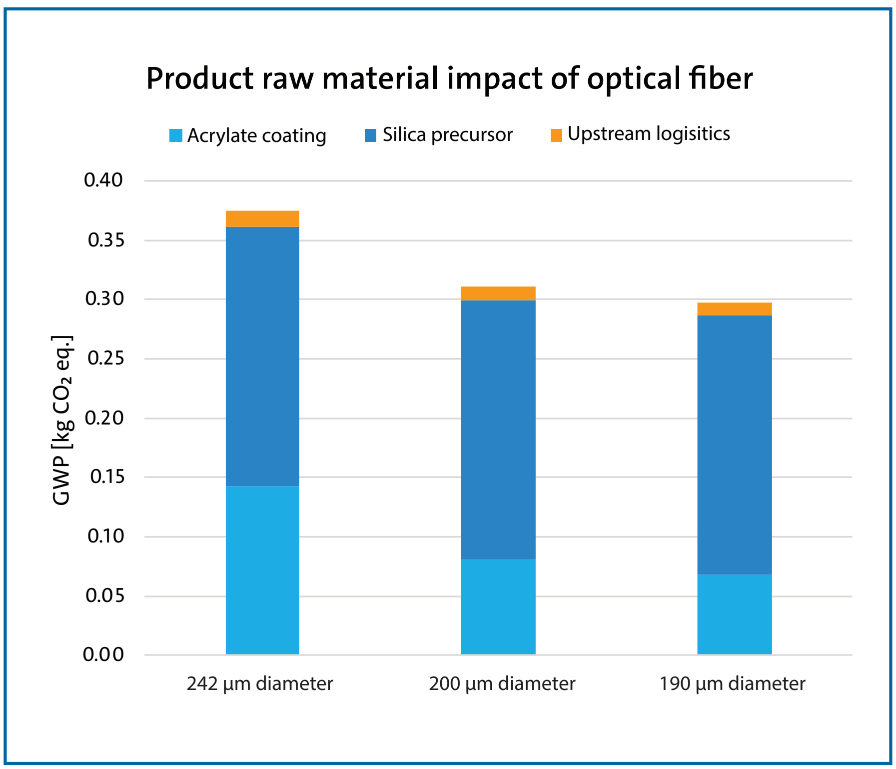


Figure 4. Coating diameter reduction impact on optical fiber carbon footprint

High-performance fibers with reduced coating diameters like Corning's SMF-28® Contour optical fiber portfolio enable increased cable and duct density while reducing size and materials in cables and solutions. This poses yet another opportunity for further improvements in optical fiber CF. As the impact of raw material is reduced, the fraction of contribution from electricity increases, with conversion to renewable electricity providing an opportunity to significantly reduce cable's CF.

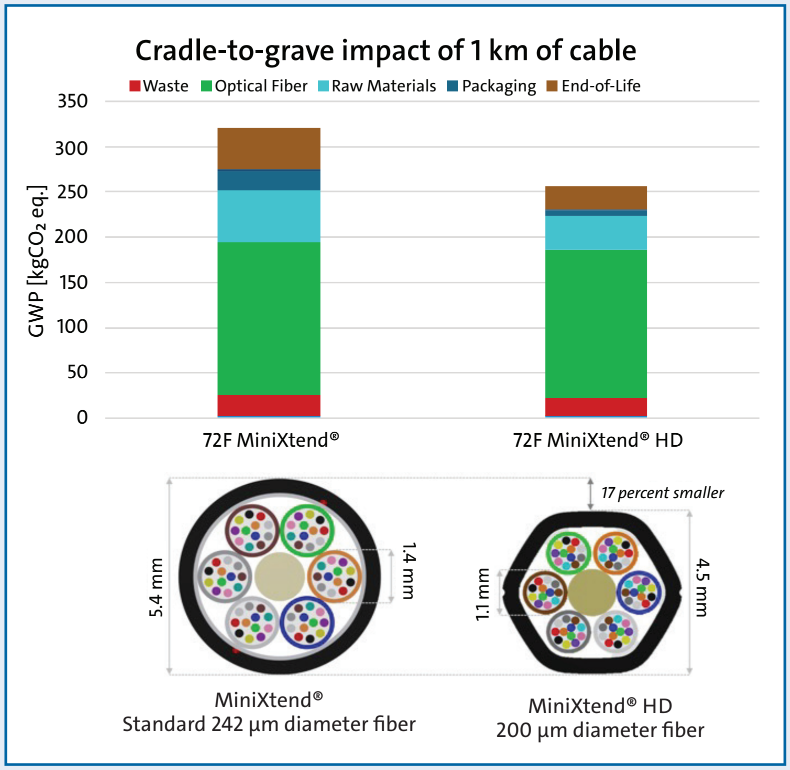


Figure 5. Cable carbon footprint is improved with reduced diameter optical fiber

Manufacturing impact and contribution of electricity

Upstream impact of materials is an important part of Cradle-to-Gate studies, but it does not consider the whole picture. The utilities required to convert those materials into the final product, optical fiber, were also included in the LCA. As previously mentioned, fiber production is an electricity-intensive process. Process water, thermal energy, and waste have a negligible impact compared to the electricity requirements for manufacturing optical fiber and to the raw materials previously discussed.

Corning's LCA study uses data from relevant factories, which use electricity from the standard grid mix. Since electricity impacts 70-80% of the total optical fiber CF, the value of continued energy efficiency efforts and a greener electricity mix is clear. Corning is on a path to 100% renewable electricity in the next four to six years in the United States and Europe, where most of its optical fiber is manufactured. The impact of renewable electricity was studied and the LCA confirms that CF can decrease by up to 70% leading to a 0.70 kg CO_2eq/km value [9], further improving the current CF advantage over copper-based networks by a factor of 3.

The future is fiber

More than ever, the world depends on data, and optical fiber has demonstrated superior capabilities over all other alternatives, offering massive capacity that expands the bandwidth of human potential while reducing power consumption and embodied carbon.

The digital divide persists and to connect the unconnected, additional needs for data processing, storage, and analysis arise, setting the stage for growth in cloud data centers. Furthermore, AI, machine learning, the rise of remote working and future technologies will drive additional network growth and data processing at high speeds.

The industry must scale in a sustainable way, and optical fiber offers the best pathway from an economic, environmental, and social aspect. Compared to copper-based networks, optical fiber reduces energy consumption by up to 54%, reduces operational costs due to lower maintenance requirements, and offers high-performance and high reliability that lasts a lifetime. Optical fiber also provides an opportunity to reduce embodied carbon by at least 85,000 times when considering the materials and processes needed to achieve the same transmission capacity over the same reach in a copper network. This improvement potentially increases by a factor of 3 when 100% implementation of renewable electricity in optical fiber manufacturing is achieved.

Looking a decade ahead, the ICT industry has a tremendous opportunity to move the world forward – by connecting the unconnected and building out the cloud to serve the data demands of tomorrow. Making sustainable choices, quantified by industry-recognized and transparent studies, is our responsibility.

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