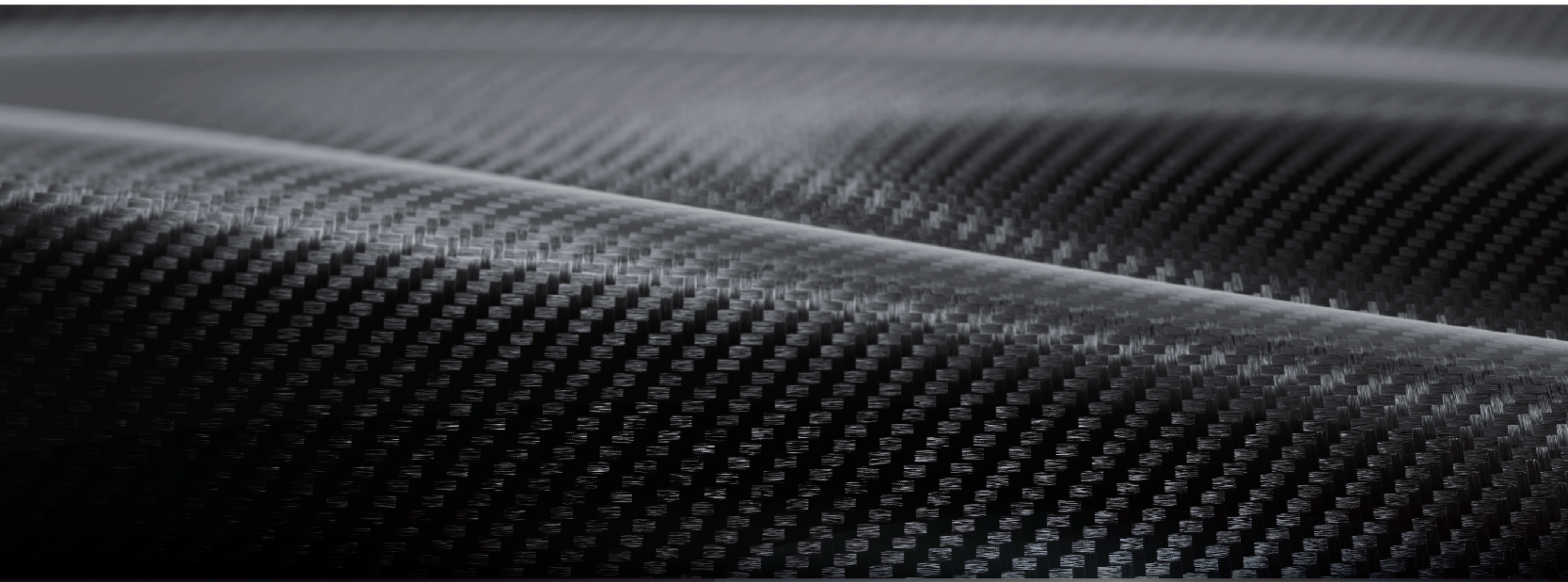
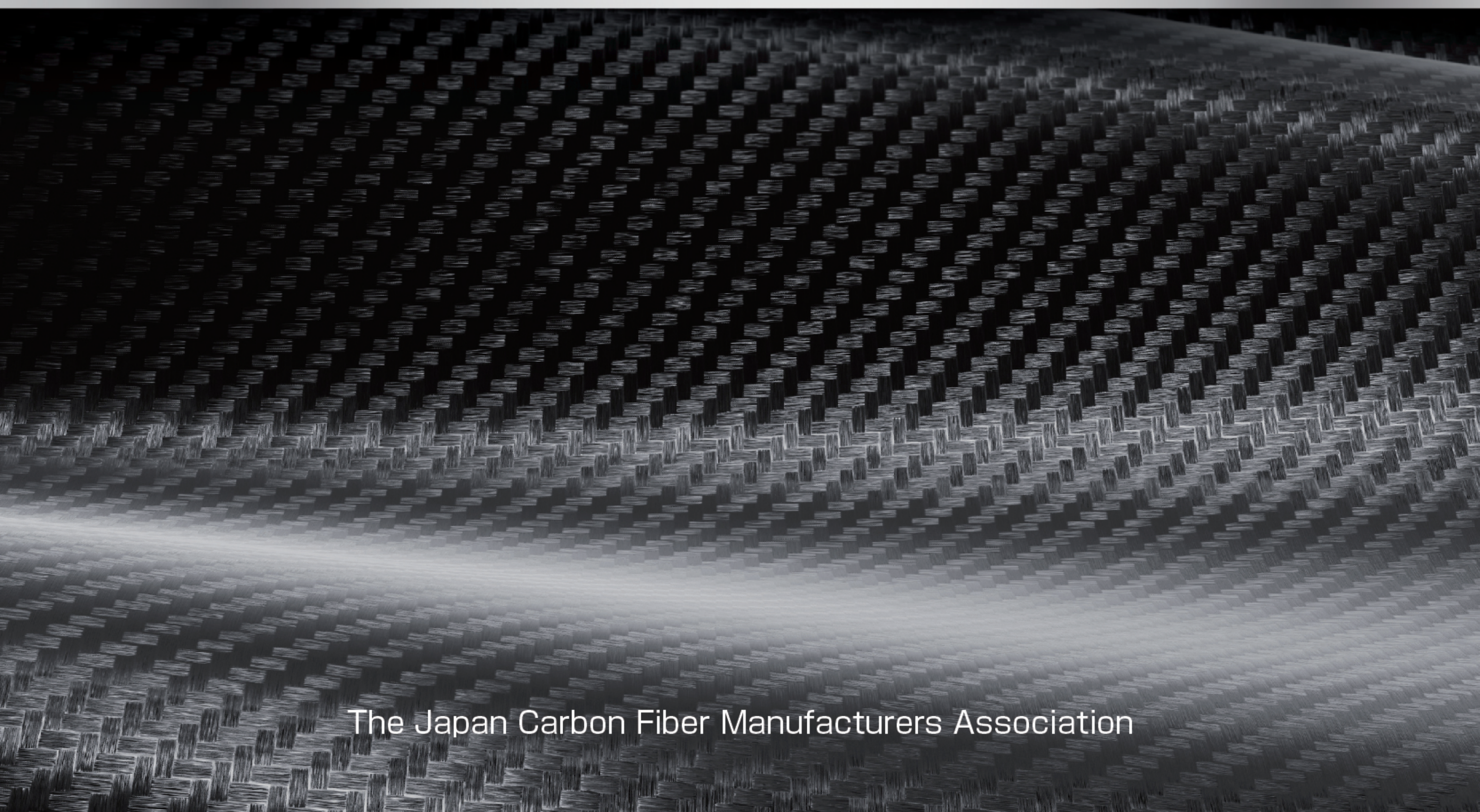
JCFA
Japan Chemical Fibers Association



Carbon fiber sustainability vision 2050

28 October 2022

Preliminary



The Japan Carbon Fiber Manufacturers Association

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I. Introduction

To date, the Japan Carbon Fiber Manufacturers Association Committee of the Japan Chemical Fibers Association (hereafter referred to as "The Japan Carbon Fiber Manufacturers Association") has promoted the quantification and appeal of the CO_2 emission reduction effect of using carbon fibers (CFs) via life-cycle assessment (LCA) models for objects, such as aircraft, automobiles, and wind turbines. In terms of recycling, a pilot plant was constructed in Omuta City, Fukuoka Prefecture, in the late 2000s, as a subsidized project by the Ministry of Economy, Trade and Industry of Japan, and a feasibility study on CF recycling was conducted. Based on the activities of the Carbon Fiber Recycling Technology Development Association from 2012 to 2014, this feasibility study has continued with the eventual goal of commercialization. In this way, the Carbon Fiber Recycling Technology Development Body has made significant accomplishments in terms of CFs as materials that contribute to the global environment.

In October 2020, the Japanese government set an ambitious goal of achieving carbon neutrality by 2050. Maximum efforts from the public and private sectors are essential for achieving this goal, and this should be linked to economic growth in Japan, creating a continuous cycle between the economy and environment.

The Carbon Fiber Manufacturers Association would like to reconsider how to realize a carbon-neutral and sustainable society and create jobs and to grow while contributing to the achievement of goals common to all humankind. To achieve these goals, here, we summarize the long-term outlook for the field of global environmental conservation, where CFs can make the greatest contribution, and we describe our vision.

The companies in the Carbon Fiber Manufacturers Association will continue to undertake these challenges; however, multiple challenges are difficult to handle through the efforts of our industry alone. We would like to ask for the continued support of the government and the understanding and cooperation of all CF users.

The Japan Carbon Fiber Manufacturers Association Committee,
Japan Chemical Fibers Association
October, 2022

II. About CFs

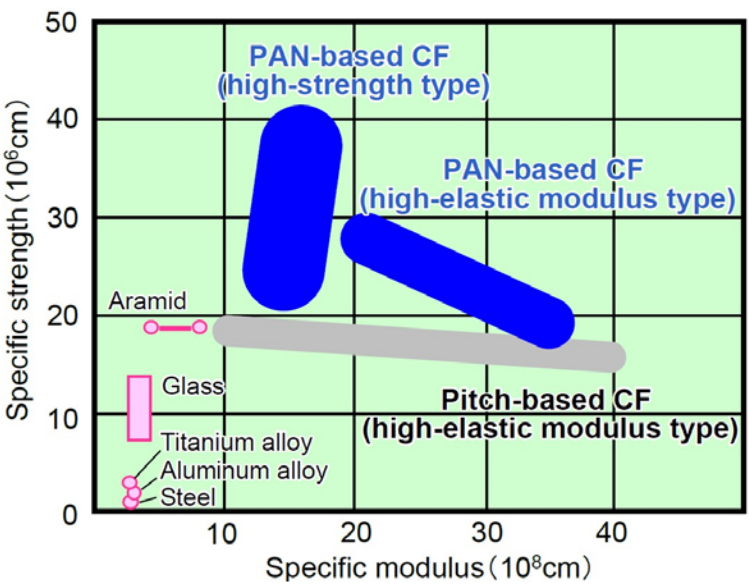
CFs are defined as follows in the ISO and JIS standards. Based on the type of precursor[1], CFs are classified as polyacrylonitrile (PAN)-type, pitch-type, etc.

ISO 2076 "A fiber containing at least 90% by mass of carbon obtained by thermal carbonization of organic precursors."

JIS L204-2 "A fiber composed of carbon at a mass ratio of 90% or more, obtained by heating and carbonizing an organic fiber precursor."

1. Characteristics of CFs

CFs have a weight that is one-fourth that of steel, a strength per unit weight (specific strength) that is 10 times that of steel, and a resistance to deformation per unit weight (specific elastic modulus) that is seven times that of steel, making them a light, strong, and difficult-to-deform material. Other properties include resistance to thermal expansion, good dimensional stability, excellent durability (such as rust resistance, fatigue, and creep resistance), excellent X-ray transparency, chemical resistance, heat resistance, and electrical conductivity. Therefore, CFs are fibers with various functions.



Table/Figure 1. Specific strength and specific elastic modulus of CFs

[1]Precursor: Here, it refers to the prior form of CF.

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Table/Figure 2 shows a comparison of the main physical properties (representative values) of PAN-based CFs, anisotropic pitch-based CFs (graphite thread), and isotropic pitch-based CFs (graphite).

Item		PAN-based CF (standard/medium-elastic-modulus type)	PAN-based CF (high-elastic-modulus type)	Isotropic pitch-based CF (graphite)	Anisotropic pitch-based CF (graphite thread)	Graphite monocrystal (reference)
Fiber diameter [μm]		5～8	5～6	12～18	7～11	
Density and structure	Density [g/cm³]	1.74～1.82	1.75～1.95	1.58～1.62	2.06～2.22	2.26
	Surface spacing (d_{002}) [nm]	0.345～0.355	0.339～0.345	0.3414～0.3438	0.3368	0.3354
	Crystallite size (*La*&*Lc*) [nm]	4～6 (*La*) 2～5 (*Lc*)	5～7 (*La*) 4～10 (*Lc*)	2～3	39 (*La*) 38 (*Lc*)	＞100
Physical properties along the fiber axis (a-axis)	Tensile strength [MPa]	3500～7000	3800～4900	500～850	2600～3800	1×10^5
	Elastic modulus [GPa]	200～330	340～640	20～40	420～900	1060
	Elongation [%]	1.5～2.2	0.7～1.4	2	0.3～0.7	－
	Thermal conductivity [W/m・K]	7～15	20～200	4～23	～900	1950
	Volume resistivity [μΩ・m]	12～20	7～12	30～50	2～8	0.4 (natural graphite crystal)
	Linear thermal expansion coefficient [10^{-6}/K]	-0.3～-0.6	-0.6～-1.2	1.7	-1.1	-1～1 (minimum near room temperature, zero near 400° C)

Table/Figure 2. Comparison between major textures/structures and physical properties of various CFs

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2. PAN-based CFs

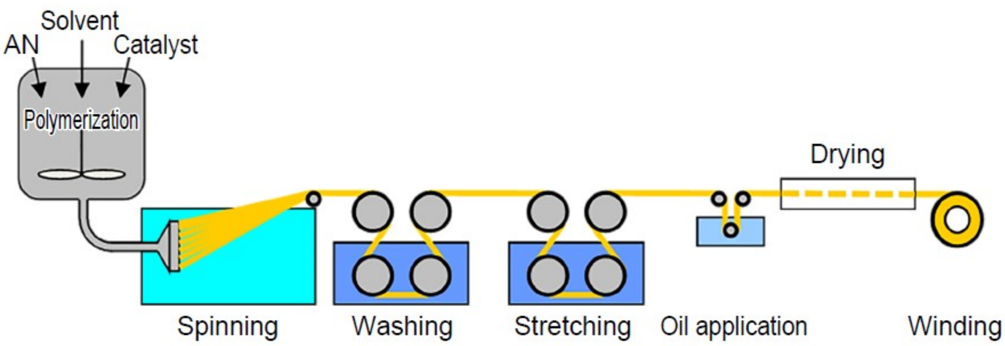
(1) Manufacturing method

The manufacturing of PAN-based CFs is roughly divided into two processes: 1) a spinning process, where acrylic fibers are obtained as a raw yarn by polymerizing the monomer acrylonitrile (AN), and 2) a calcination process, where acrylic fibers are made flameproof and carbonized to obtain CFs.

① Spinning process

AN and a solvent are mixed, a catalyst is added and polymerized, and a spinning dope is prepared.

The spinning dope is extruded into a poor solvent in the form of fibers and solidified. Subsequently, it is washed with water (washing), stretched, oiled, dried, and wound up as an acrylic fiber.



Table/Figure 3. Manufacturing method of PAN-based CFs (raw thread)

② Calcination process

First, acrylic fibers are heat-treated in the air at 200–300℃ to stabilize them, thereby converting them into flame-resistant yarns with a high heat resistance (flame proofing process). Next, elements other than carbon are burnt off at an ultra-high temperature of 1000–3000 ° C in an inert gas to obtain fibers that have a graphite structure (carbonization/graphitization process). The fired CFs are surface-treated to increase the adhesion to the matrix resin, and a sizing agent is added to improve the handling of the fibers, after which they are wound on a bobbin and made into the final product, namely CFs.

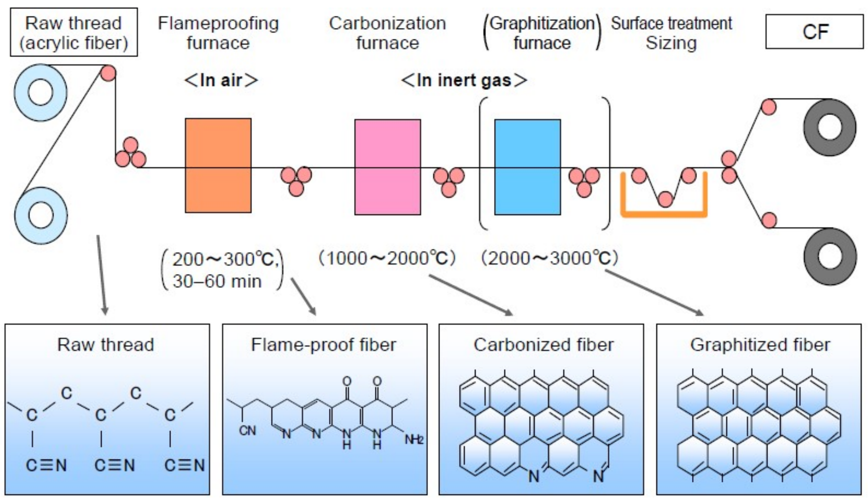
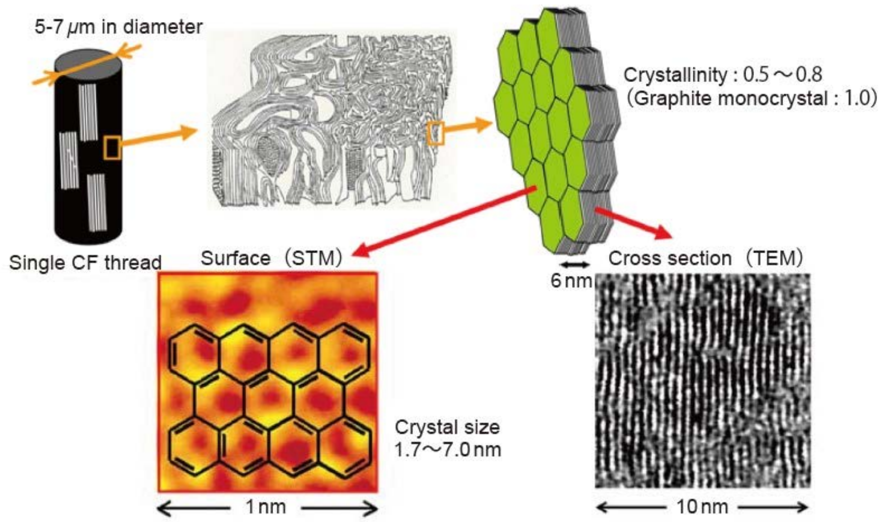


Figure 4. Manufacturing method for PAN-based CFs (calcination)

(2) Fiber structure

In a single CF, sheet-like graphite crystals are arranged parallel to the fiber direction. Observation of the surface and sides via scanning tunneling microscopy (STM) and transmission electron microscopy (TEM) shows graphite crystals lined up, as presented in the photograph in Fig. 5; however, in reality, a single CF has a random onion-like structure[2].

The crystallinity is approximately 0.5-0.8, and approximately half of the CFs used for general purposes are amorphous. The crystal size varies considerably depending on the calcination temperature; however, in the case of general products, it is approximately 1.7 nm for general-purpose grades and approximately 7 nm for high-elastic-modulus grades.



Table/Figure 5. CF structure

[2]Onion structure: multi-layer structure similar to that of an onion

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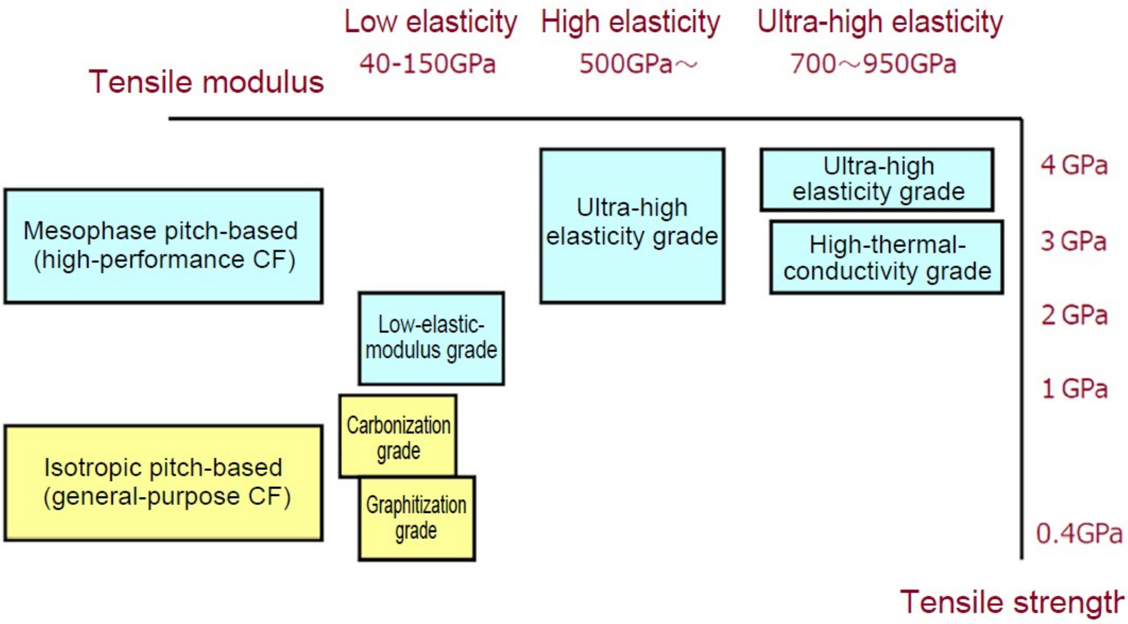
3. Pitch-based CFs

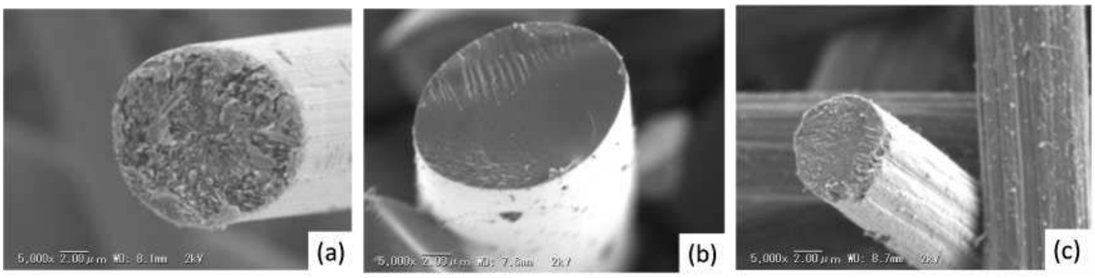
For pitch-based CFs, naphtha-derived ethylene bottom oil (petroleum-based) or coal tar (coal-based) are used as the initial material, low-boiling-point components are removed, and the material is made heavier by applying heat treatment to obtain a pitch suitable for spinning. After the pitch is extruded through a narrow nozzle to form a fiber, it undergoes infusibilization, carbonization, and graphitization processes and results in the CF. The fiber diameter is determined based on the magnification by which the molten pitch is drawn shortly after it is extruded through the nozzle and before it is solidified.

Pitch-based CFs are categorized into two types depending on the initial material: 1) "isotropic pitch," which is optically disordered and does not exhibit polarization, and 2) "anisotropic pitch (mesophase pitch)," where constituent molecules are arranged in a liquid-crystal state and exhibit optical anisotropy.



Table/Figure 6. Classification of pitch-based CFs

Large differences in the texture/structure and physical properties exist between anisotropic pitch-based and isotropic pitch-based CFs; anisotropic pitch-based CFs resemble natural graphite or highly oriented pyrolytic carbon, and the isotropic pitch-based CFs resemble glassy carbon. Meanwhile, CFs have an axially oriented structure and considerably differ from natural graphite, highly oriented pyrolytic carbon, and vitreous carbon in that the orientation of the carbon hexagonal network planes can be highly controlled. Fig. 7 shows SEM images of anisotropic pitch-based, isotropic pitch-based, and PAN-based CFs. All the samples used for the images are milled fibers.



Table/Figure 7. SEM images of various milled fibers:
(a) anisotropic pitch-based CF (DIALEAD™/graphite thread),
(b) isotropic pitch-based CF (Donacarbo/graphitized), and (c) PAN-based CF (Torayca$_{TM}$)

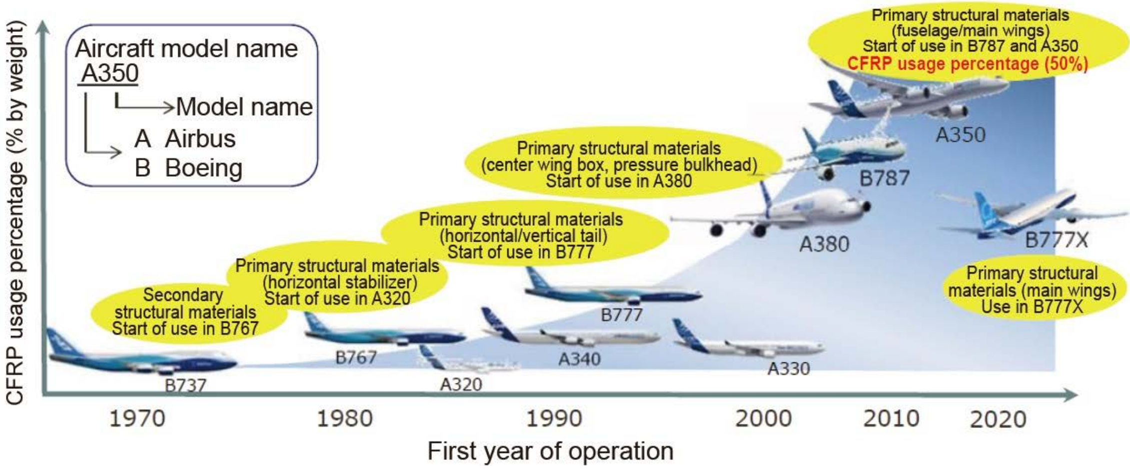
In the anisotropic pitch-based CF, the fibrils are folded. The differences in the degree of holding in this folded structure likely influence the mechanical properties, such as tensile strength and elastic modulus, and physical properties, such as thermal conductivity. The carbon hexagonal mesh plane is selectively oriented in the fiber axis direction, and it exhibits a high elastic modulus and high thermal conductivity in the fiber axis direction. In the isotropic pitch-based CF, the graphite crystallinity is low, the carbon hexagonal network plane is not developed, and the CF is not oriented. As a result, both the cross section and side surfaces of the fiber are smooth. Therefore, the mechanical properties and thermal conductivity are poor. Although the PAN-based CF has low graphite crystallinity, the carbon hexagonal mesh planes intersect and intertwine with each other and are arranged in the fiber axis direction. Thus, the PAN-based CF exhibits high mechanical strength.

III. Uses and demand for CFs

1. Main uses of CFs

① Aircraft

CF-reinforced plastics (CFRPs) are used as an essential material for improving fuel efficiency by reducing aircraft weight for multiple applications, e.g., those involving primary structural materials, such as the main wings and fuselage, and secondary structural materials, such as seats, front panels, and brake materials. In the future, these uses are expected to expand to other parts, such as engine parts.



Table/Figure 8. Changes in CFRP usage percentage in aircraft

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② Wind turbine

The installed capacity of wind power has been considerably increasing since the accident at the Fukushima Daiichi Nuclear Power Station caused by the Great East Japan Earthquake, which triggered reviews of nuclear power policy and thermal power generation that requires fossil fuels to realize a sustainable society. The size of wind-power generation blades is also increasing to improve power generation efficiency and profitability, and further expansion of CFRP demand is expected.

Table/Figure 9. Wind power generation

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③ Pressure vessels

In the United States, advances in the technologies for shale gas extraction have made the production of shale gas at low cost possible, increasing production volume and the use of natural gas vehicles. Extraction is now being conducted in small gas fields with insufficient infrastructure, such as natural gas pipelines, which were previously unprofitable. The use of CFRPs is also expanding to large compressed natural gas (CNG) tanks used for transporting gas in these regions. CFs are also expected to be used more widely in compressed hydrogen gas (CHG) tanks for fuel cell vehicles, which are expected to become widespread in the future, and in large pressure storage tanks for hydrogen stations.

(Source) Mitsubishi Chemical Corporation

Table/Figure 10. Pressure vessel

④ Automobiles

Automobile CO_2 emission regulations, such as those in Europe and Japan, are becoming stricter each year, and automobile manufacturers are accelerating the development of hybrid, fuel-cell, natural gas, electric vehicles, etc. and their efforts to reduce fuel and electricity consumption. CFRPs are effective at decreasing fuel and electricity consumption by reducing the weight of the vehicle body. Additionally, the CFRP tanks for filling hydrogen and natural gas described in (3) enable increased travel distance per fuel filling owing to high compression. Furthermore, C/C composites in which graphite is reinforced with CFs are used as electrode materials for fuel cells.

⑤ Concrete and steel infrastructure

In Japan, various types of infrastructure, such as concrete bridges, tunnels, and steel structures built during the rapid economic growth period, are aging, and the development of countermeasures is an urgent issue.

The CF sheet fabrication method involves a sheet of on-site CF impregnated with low-viscosity epoxy resin and hardened. This method is gaining popularity over conventional methods, such as steel plate and thickening fabrication methods, because it does not require heavy machinery and allows repairs in a narrow space. Furthermore, in a dedicated factory, a method has been developed for impregnating the CF bundles with resin, hardening the bundles, and attaching the plate-shaped CFRP to the frame. This method is expected to become more popular than the CF sheet fabrication method because of its stability during on-site fabrication.

Table/Figure 11. Concrete reinforcement

⑥ Industrial rolls, etc.

CFs have plate-like crystals with folded fiber cross sections, and they are regularly arranged along the fiber axis direction and characterized by a high rigidity. Therefore, mechanical parts can be fabricated with a small deflection and moment of inertia and a high natural frequency. Examples include industrial rolls, liquid crystal robot hands, industrial machine parts such as crossbars for automobile manufacturing presses, and propeller shafts.

Table/Figure 12. Long carbon-coated roll (ϕ 350 × 9200 mm)

Courtesy of Corebon AB (Sweden)

Table/Figure 13. High-precision positioning robot

⑦ Thermal insulation

Molded insulation is manufactured from CF felts and used in high-temperature furnaces that ceramics and other materials cannot withstand. This molded heat insulation is an indispensable component for silicon crystal growth furnaces used in solar cell and semiconductor manufacturing, and it reduces power consumption. It is also widely used worldwide as a heat insulation material for high-temperature furnaces, such as those for sapphire and silicon carbide crystal growth, ceramic sintering, optical fiber manufacturing, and graphite purification.

Table/Figure 14. Solar cells

⑧ Sports and leisure applications

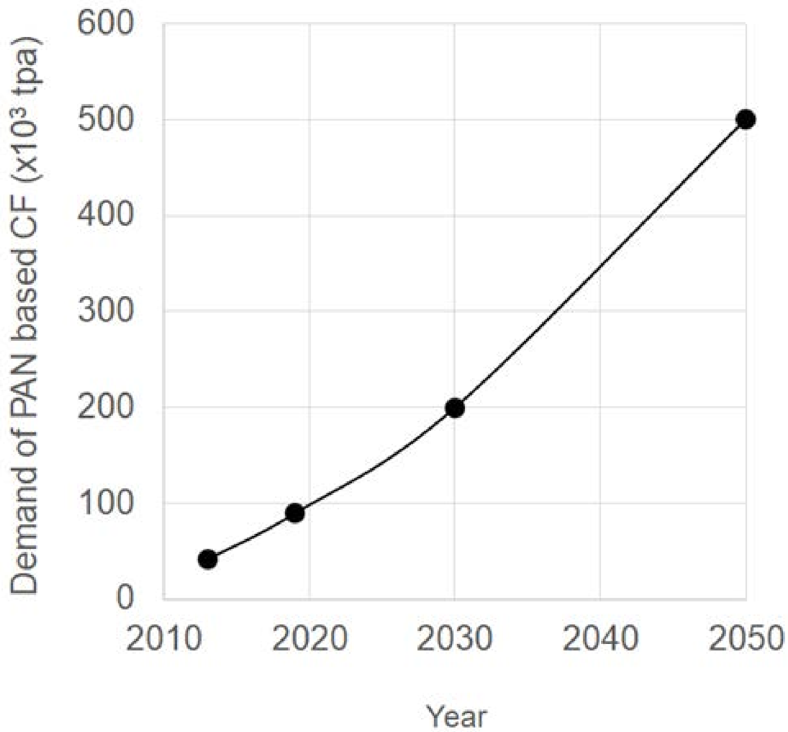
Sporting goods, such as fishing rods, tennis rackets, golf shafts, and bicycles, are popular products that most effectively incorporate the specific strength and specific elastic modulus of the CF. High-performance CFs have a high demand for use in fishing rods, and strength improvements in CFs have often progressed in tandem with improvements in fishing rods. Meanwhile, wide-frame tennis rackets (so-called "thick" rackets) are revolutionary products in terms of racket functionality (lightness and power). Additionally, for bicycles, CFs have been increasingly used in not only road race bikes but also road bikes and off-road mountain bikes, such as those used for mountain courses, which have become immensely popular. These sporting and recreational goods are expected to remain popular in the future.

Table/Figure 15. Fishing rod

2. Expected demand for CFs

Global demand for CFs increased from 42,000 tons in 2013 to approximately 90,000 tons in 2019. Although the demand temporarily decreased owing to the impact of the novel coronavirus infection, aircrafts, wind power generation, pressure vessels, automobiles, etc. are expected to continue to drive the demand with global environmental action as a tailwind.

This report is based on the assumption that global CF demand will be 200,000 tons in 2030 and 500,000 tons in 2050.



Table/Figure 16. Estimated global demand for CFs

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IV. Global warming countermeasure efforts

1. Global warming countermeasure efforts to date

To date, the Carbon Fiber Manufacturers Association has investigated the energy consumption and CO_2 emissions at the CF manufacturing stage and quantified the CO_2 emission reduction effect of CF use via LCA models for objects, such as aircraft, automobiles, and wind turbines.

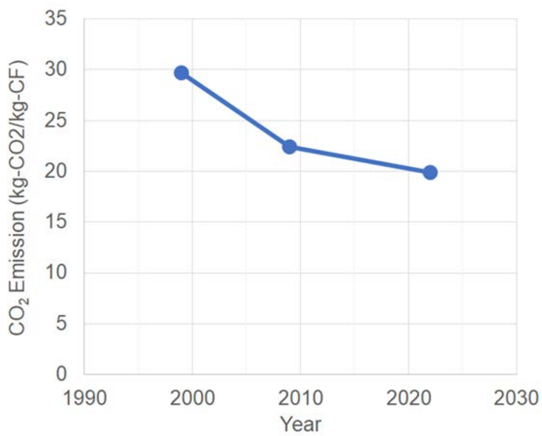
In terms of recycling, a pilot plant was constructed in Omuta City, Fukuoka Prefecture in the late 2000s as a subsidized project by the Ministry of Economy, Trade and Industry of Japan, and a demonstration study of CF recycling was conducted.

(1) CF life cycle inventory (LCI)

From FY1997 to FY1998, upon the request and guidance of the then Ministry of International Trade and Industry of Japan, the Carbon Fiber Manufacturers Association began to investigate LCI data for CFs in cooperation with the composite material LCI data fabrication project. The results were reported in the "Investigative report on the analysis of inventory data for composite materials" (July 1999, Society of Japanese Aerospace Companies). Subsequently, LCI data were published in FY2006, FY2009, and FY2017.

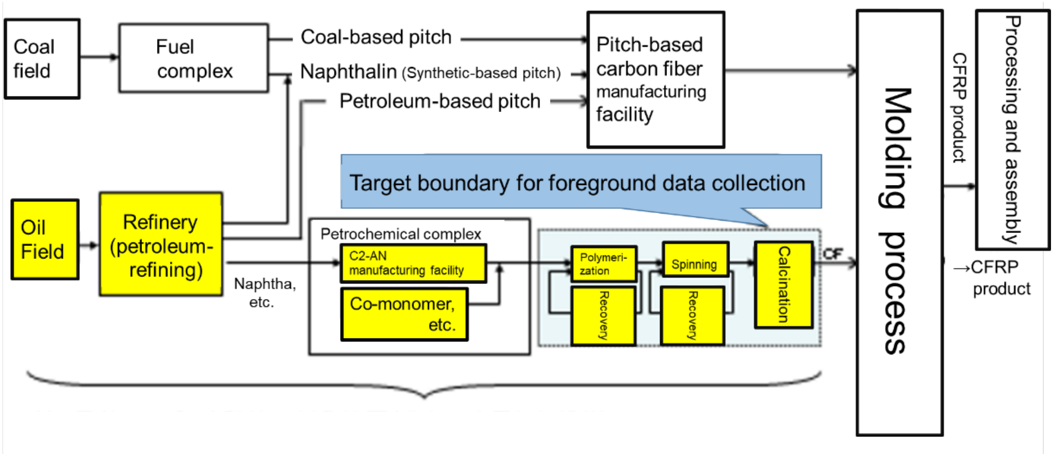
For the published values since FY2009, LCI data based on the latest production results in the main production line of high-strength CFs, which is the main brand of PAN-based CFs (elastic modulus of 230–250 GPa, filament count of 12K (800 tex)–24K (1,600 tex)), were aggregated, and the results were registered with the Japan LCA Forum.

Fig. 17 shows the shifts in CO_2 emissions for manufacturing 1 kg of CF, with the 2022 published value included.



Table/Figure 17. Shifts in CF LCI

The investigation included the main raw materials and auxiliary raw materials/materials used in the PAN polymerization, precursor spinning, and CF calcination processes, as well as various utilities (electric power, water, fuel, etc.). Additionally, the main raw materials, auxiliary raw materials, and materials used in these processes were evaluated retroactively to the crude oil extraction stage.



Note: Range covered by performing cumulative LCI data calculation (indicated in yellow)

Table/Figure 18. Scope of calculation including retroactive analysis of the raw material

Based on these LCI data, a Carbon Fiber Manufacturers Association model of LCA for airplanes, wind power generation, and automobiles was created, and CFs were found to be highly effective at reducing CO_2 emissions during the use stage. The Carbon Fiber Manufacturers Association model is described in Section 2 (1) “Contributions to reducing CO_2 emissions at the product use stage.”

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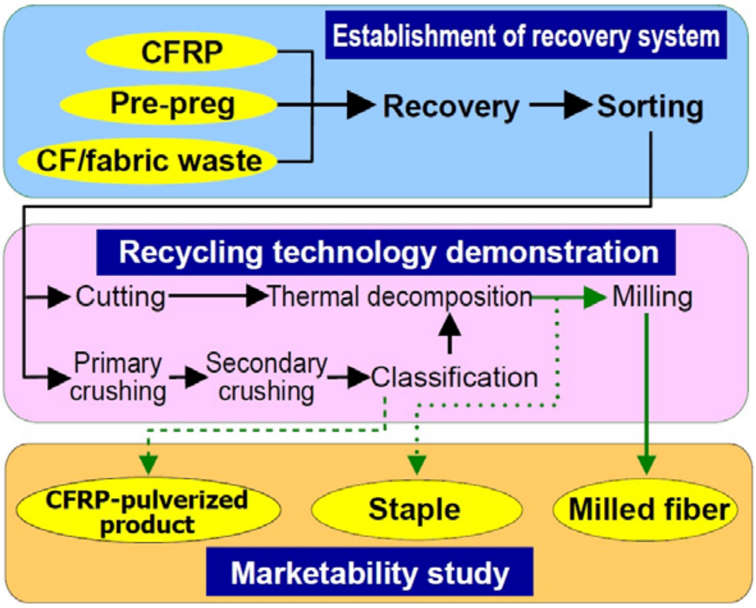
(2) Technological development of CF recycling

In 1997, the Carbon Fiber Manufacturers Association began investigating effective disposal methods based on the judgment that the conventional landfill disposal method could no longer be relied upon as the CF market grew. After subsequently being entrusted with the standard certification research and development project “Standardization of recycled carbon fiber-reinforced plastic (CFRP) pulverized products” from FY2000 to FY2002 commissioned by the New Energy and Industrial Technology Development Organization and Ministry of Economy, Trade and Industry, the association has continued to conduct survey research and demonstration studies on CF recycling.

Fiscal year	Research theme	Implementing body
Around 1997	Survey research on methods for replacing CFRP landfill disposal	Domestic PAN-based CF manufacturer
2000~2002	NEDO-commissioned research “Standardization of recycled CFRP pulverized products” -Development of CFRP pulverization and classification technology -Development of CFRP resin(thermal) decomposition/removal technology -Development of milled CF recycling technology	
2003~2005	Independent research (construction of basic technology)	The Carbon Fiber Manufacturers Association
2006~2008	Subsidized project of the Ministry of Economy, Trade and Industry “Research and development of energy reduction technology for CF manufacturing” -Recycling process flow design and marketability research -Pilot plant design and construction, verification of waste material recovery -Pilot plant demonstration operation, evaluation of recycled products	
2009~2011	Joint research with Omuta City, Fukuoka Prefecture “Research on recycled CF” -Recycled CF manufacturing for application development project (prefecture/user) -Quality improvement of recycled, milled CFs, prototyping of short-fiber CFs	
2012~2014	Carbon Fiber Recycling Technology Development Body activities	Carbon Fiber Recycling Technology Development Body (domestic PAN-based CF manufacturers)
2015~	Technological development by individual companies →commercialization	Each company

Table/Figure 19. Recycling efforts of the Carbon Fiber Manufacturers Association

From 2006 to 2011, as a project subsidized by the Ministry of Economy, Trade and Industry, a pilot plant with a processing capacity of 700 tons per year was constructed in Eco Town in Omuta City, Fukuoka Prefecture, and a demonstration study was conducted.



Table/Figure 20. Image of the CF recycling pilot plant (left) and diagram of the CF recycling flow (right)

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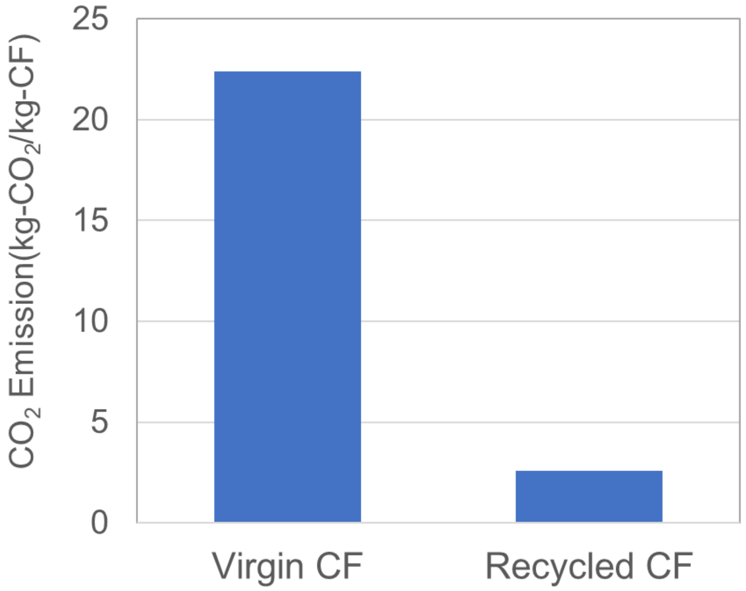
Since FY2012, this research has been conducted by the Carbon Recycling Technology Development Association, which was established by three PAN-based carbon manufacturers to further develop the technology. A target of 2.6 kg CO_2/kg CF was obtained as the CO_2 emission for the manufacturing of 1 kg of recycled CFs.

The Carbon Fiber Recycling Technology Development Association was dissolved in March 2015 after it achieved its initial goal of establishing a manufacturing technology for recycled CFs.



(Note) As of 2015

Table/Figure 21. Unit CO_2 emissions during production of virgin and recycled CFs

2. Long-term vision for global warming countermeasures

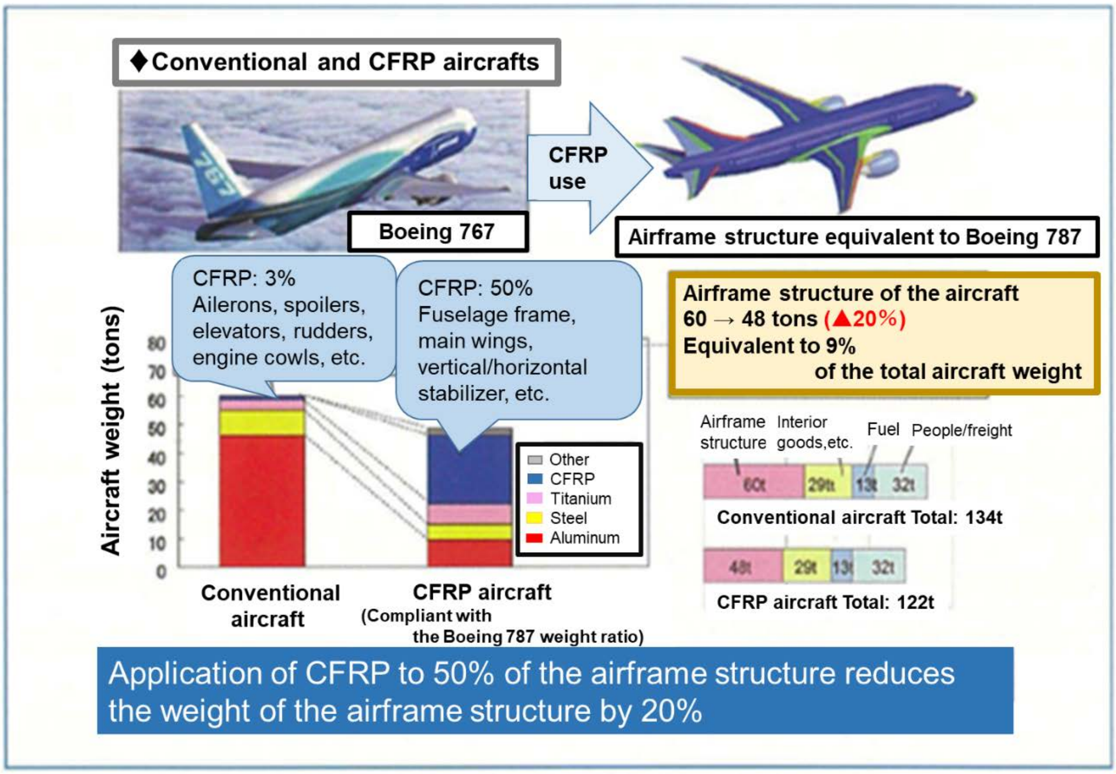
(1) Contributions to reducing CO_2 emissions at the product use stage

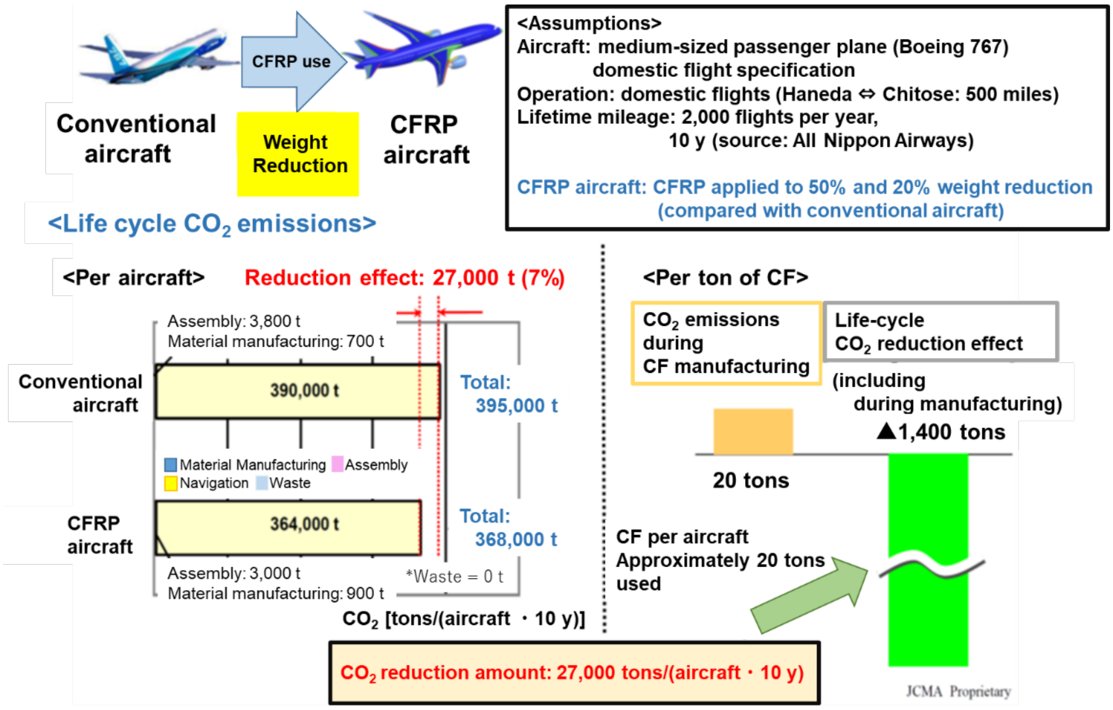
In this chapter, we show that CF is an excellent environmentally friendly material in terms of LCA.

The LCA is a method of calculating CO_2 emissions and environmental pollutants. It is used to scientifically, quantitatively, and objectively evaluate the numerical burden on the environment throughout the life cycle of a given product, from the collection of raw materials, manufacturing, and distribution to its use in society and eventual disposal.

① Aircrafts

The application of CFRPs in aircrafts has a very large CO_2 reduction effect owing to the improved fuel efficiency. Conventionally, CFRPs have only been partially used for ailerons and spoilers; however, expanding it to the fuselage frame, main wings, and vertical/horizontal stabilizer has enabled its use in 50% of the airframe structure. This has provided an airframe structure that is 20% lighter and a fuel efficiency that has improved by approximately 7%. The use of these aircrafts for 10 years can reduce CO_2 emissions by 27,000 tons per aircraft.

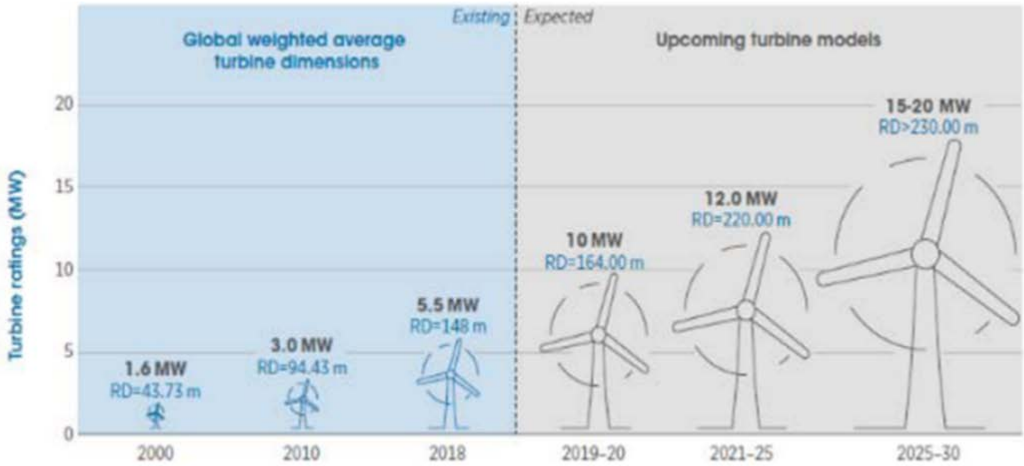




Table/Figure 22. Aircraft LCA of the “Carbon Fiber Manufacturers Association model”

② Wind turbine

The use of CFRPs in wind turbine generator blades has made it possible to increase the diameter of wind turbines to over 100 m. The power generation capacity of wind turbines is proportional to the square of the blade length; thus, the power generation capacity per unit has considerably improved, with 10-MW offshore wind power plants now being built. If these wind turbines are used for 25 years, CO_2 reductions of 318,000 tons per unit can be achieved over that of thermal power generation (average values of coal-fired power plus oil-fired power).



Source: International Renewable Energy Agency (IRENA) material

Table/Figure 23. Different offshore wind powers as a function of turbine diameter (average)

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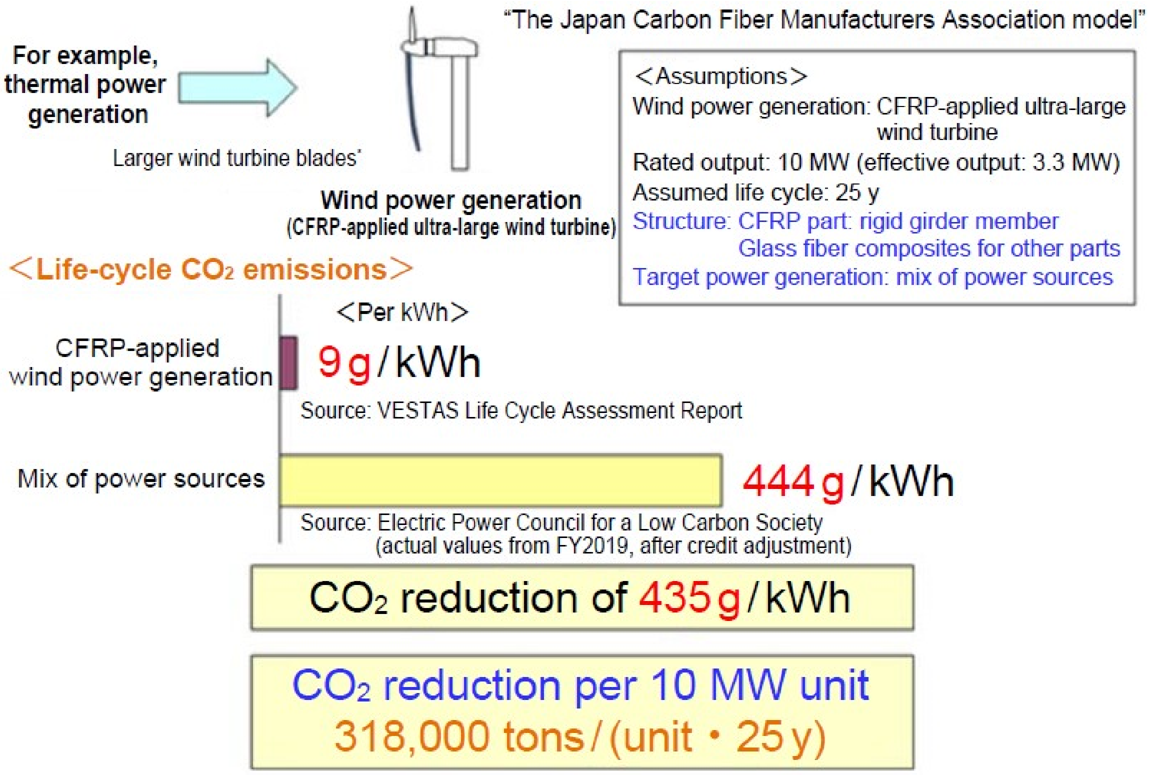
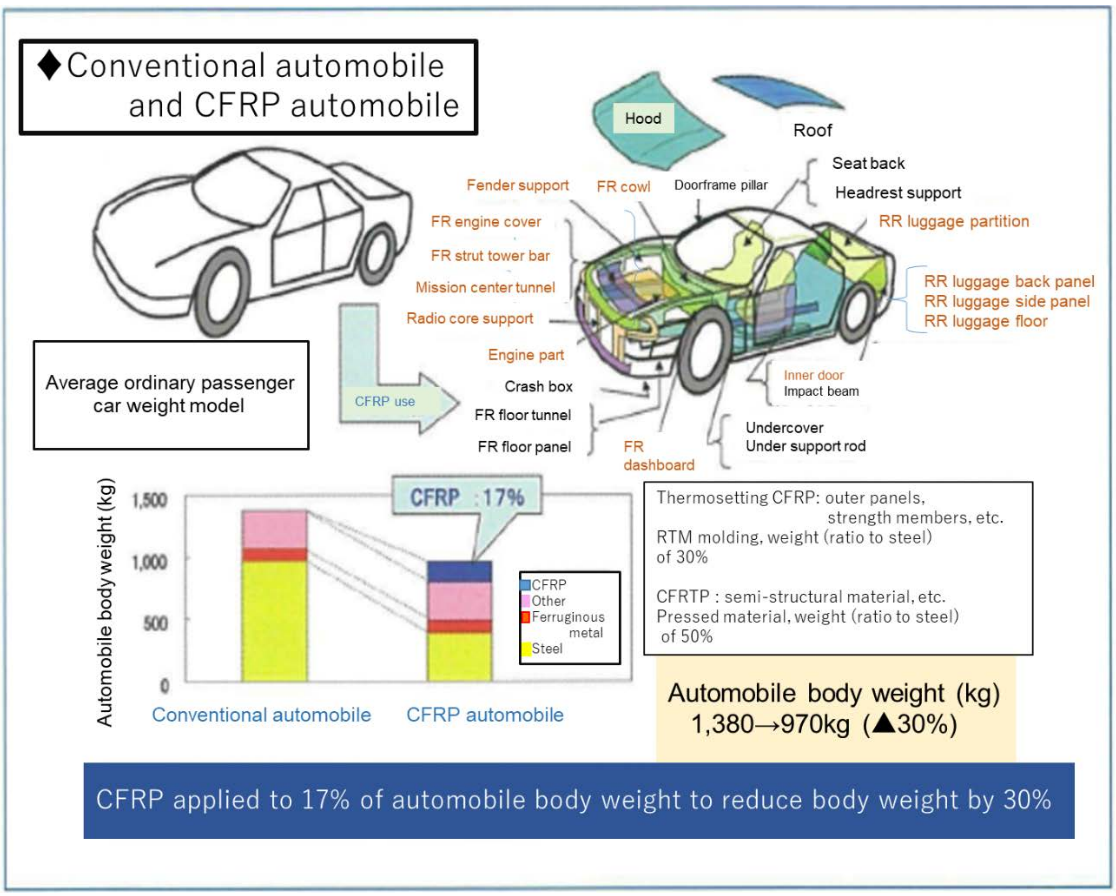
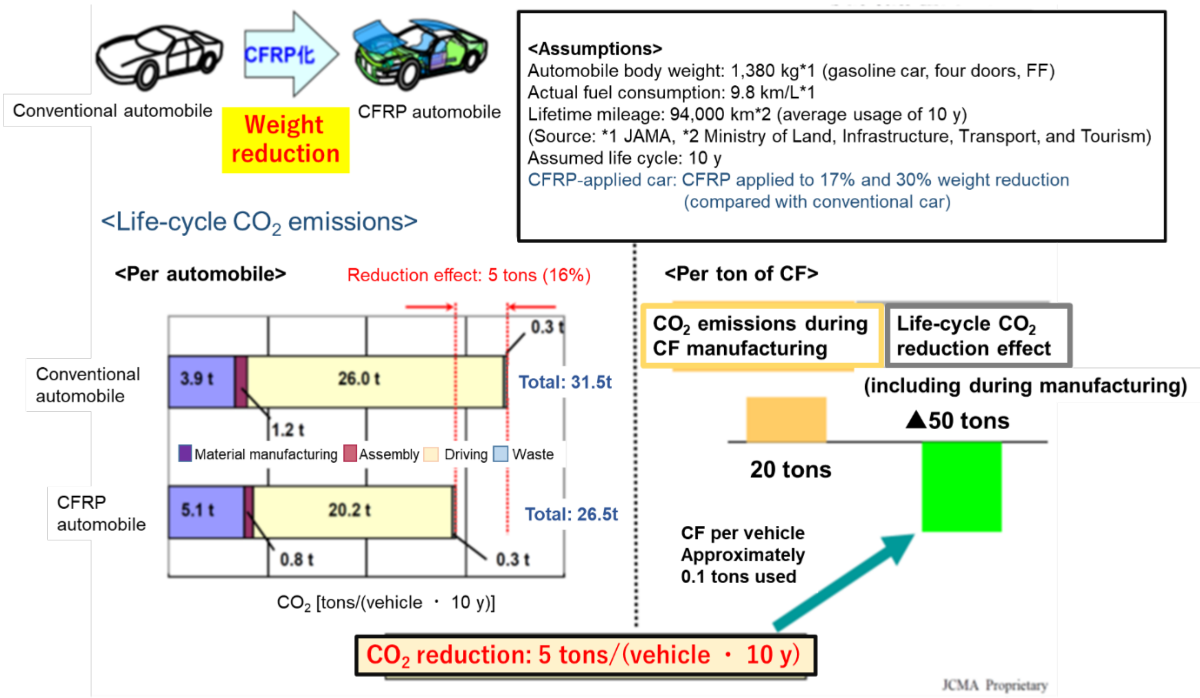


Table/Figure 24. Wind turbine LCA "Carbon Fiber Manufacturers Association model"

③ Automobiles

The application of CFRPs to 17% of the body weight of an average standard-sized automobile model can reduce its body weight by 30% compared to an automobile body that has conventional mild steel plates on it, improving fuel consumption by 22%. The use of this automobile for 10 years will reduce CO_2 emissions by 5 tons per automobile.

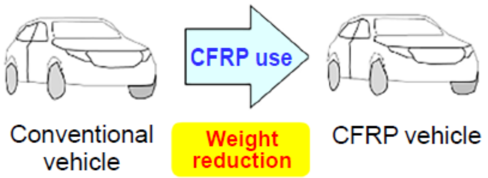




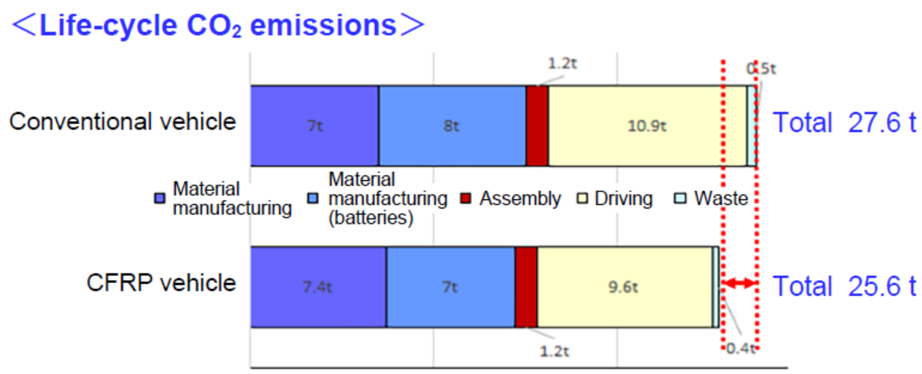
Table/Figure 25. Automobile LCA "Carbon Fiber Manufacturers Association model"

④ Electric vehicles

The application of CFRPs to 16% of the body weight of a mid-sized electric SUV can reduce its weight by 16% compared to a body made primarily of high-tensile steel and aluminum, and it will reduce batteries by 13%. Fuel consumption will improve, and driving this vehicle 100,000 km in Japan or 150,000 km in Europe can reduce CO_2 emissions by 2 tons per vehicle.



<Assumptions>
Vehicle weight: 2,500 kg (mid-sized SUV)
Battery case total weight: 650 kg (including battery of 400 kg), total power consumption: 80 kWh
Electricity consumption: 245 Wh/km, travel distance of 400 km per charge
Lifetime mileage: 100,000 km (Japan), 150,000 km (Europe)
Electric power CO_2 emission factor: 0.436 kg/kWh (Japan), 0.296 kg/kWh (Europe)
Assumed life cycle: 10 y
CFRP-applied vehicle: 16% weight reduction (compared to a conventional vehicle)



CO_2 reduction: 2.0 tons / (vehicle・Japan, 10 y)

Table/Figure 26. Electric vehicle LCA "Carbon Fiber Manufacturers Association model"

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(2) Efforts to reduce CO_2 emissions at the CF manufacturing stage

As mentioned above, CFs are environmentally friendly materials that considerably contribute to energy conservation at the customer use stage. However, achieving the carbon-neutral society advocated by the government requires further efforts to reduce CO_2 emissions at the CF manufacturing stage.

Fig. 27 shows possible CO_2 emission reduction measures at the CF manufacturing stage. We have summarized our vision of how much CO_2 emission can be technically reduced by these measures during the manufacturing of 1 kg of CFs.

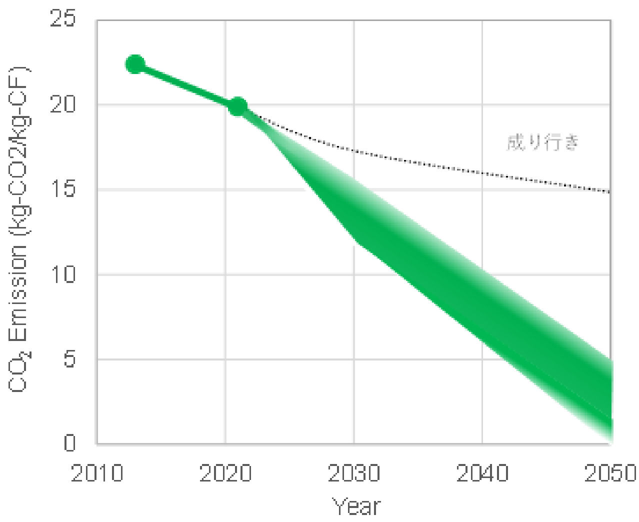
Additional industry efforts		- Reduction of CO_2 emission factor of purchased electric power (each electric power company) - Zero-emission grid power supply - CO_2 reduction in upstream processes
Intra-Industry efforts		- Improved productivity and product rate in CF manufacturing process - Fuel conversion for in-house power plants, steam production plants, etc. (LNG, bio-based fuel) - Part of the raw material acrylonitrile is also bio-derived
	Requires external collaboration	- Promotion of CF recycling and improvement of recycled CF distribution ratio - CCS/CCU technology introduction, etc.

(Note) CCS/CCU: Abbreviation for “carbon dioxide capture and storage/utilization”

Table/Figure 27. Technologies for CO_2 emission reductions during CF manufacturing

First, the black-dotted line in the figure shows additional industry efforts (outcomes), such as the manufacturing process of raw CF materials (raw material mining to refining) and external procurement of utilities, including purchased electric power. Additionally, the green line (band) shows the effect of implementing CO_2 reduction measures as intra-industry efforts, such as process improvement during CF manufacturing.

There is a wide range for the vision value because it varies depending on the market distribution rate of recycled CFs and the status of CCS/CCU technology introduction. Especially for CCS/CCU, one key aspect is whether the technology can be used cheaply even in processes with relatively low CO_2 concentrations.



Table/Figure 28. Vision value of unit CO_2 emission during CF manufacturing

When we predicted the CO_2 emissions reduction effect (outcome) that is expected when one ton of CF is manufactured only by additional industry efforts, the results showed that there will be a 21% decrease by 2030 and 33% decrease by 2050 (both relative to FY2013).

In addition, when one ton of CFs is manufactured, the CO_2 emissions are expected to be reduced by 30–47% by 2030 due to intra-industry efforts such as fuel conversion and process improvement at CF manufacturing sites and by increasing the amount of recycled CF in circulation. Furthermore, continuing and strengthening these efforts would reduce CO_2 emissions by 78–97% by 2050 (both 2030 and 2050 values are relative to FY2013). The slight CO_2 emissions that remain are derived from the reaction products of raw materials; thus, these emissions could be practically zero if raw materials are changed to biologically sourced ones or introducing technologies that absorb, store, and re-use CO_2 (CCS/CCU).

Meanwhile, regarding the total CO_2 emissions related to CF manufacturing, although the emissions are expected to increase up until approximately 2030 relative to FY2013 due to increased demand, total CO_2 emissions are expected to decrease significantly by 2050 as a result of continuing and strengthening various energy conservation measures and by increasing the amount of recycled CF in circulation.

(3) Recycling efforts

As of 2022, CO_2 emission during the production of recycled CFs was 2.6 kg CO_2/kg CF, which was approximately one-eighth that of virgin CFs, and one effective method to reduce CO_2 emissions during CF manufacturing is to increase the market distribution of recycled CFs.

Further developing the recycling business requires not only establishing technologies for recycling CFs from CFRPs but also recovering CFRP waste materials, assessing the quality of recycled CFs, and developing applications in an integrated manner. This is difficult for the CF industry to tackle alone; thus, there is a need for the government, user industries, recycling companies, research institutions, etc. to work together to build a business scheme.

① Amount of generated CFRP waste material and the recycled CF market

According to a Ministry of Economy, Trade and Industry survey[3] and others, as of 2020, the amount of used CFRP waste materials discharged was estimated at 46,500 tons, and the amount of CFRP waste materials discharged from the CFRP manufacturing process was estimated at 10,500 tons. Meanwhile, less than 10% undergoes material recycling, and most undergoes thermal recycling or ends up in a landfill.

② Recycling companies/research institutions and recycling methods worldwide

Recycled CF manufacturing technology can be broadly divided into the thermal decomposition method (using superheated steam), liquefaction method (solvent decomposition method, supercritical/subcritical fluid method), physical pulverization method, and electrolytic oxidation method; however, the thermal decomposition method and its derivatives are at the stage of commercialization or practical application.

At the end of the book, we list worldwide recycling companies (manufacturers), recycling research institutions, and their recycling methods.

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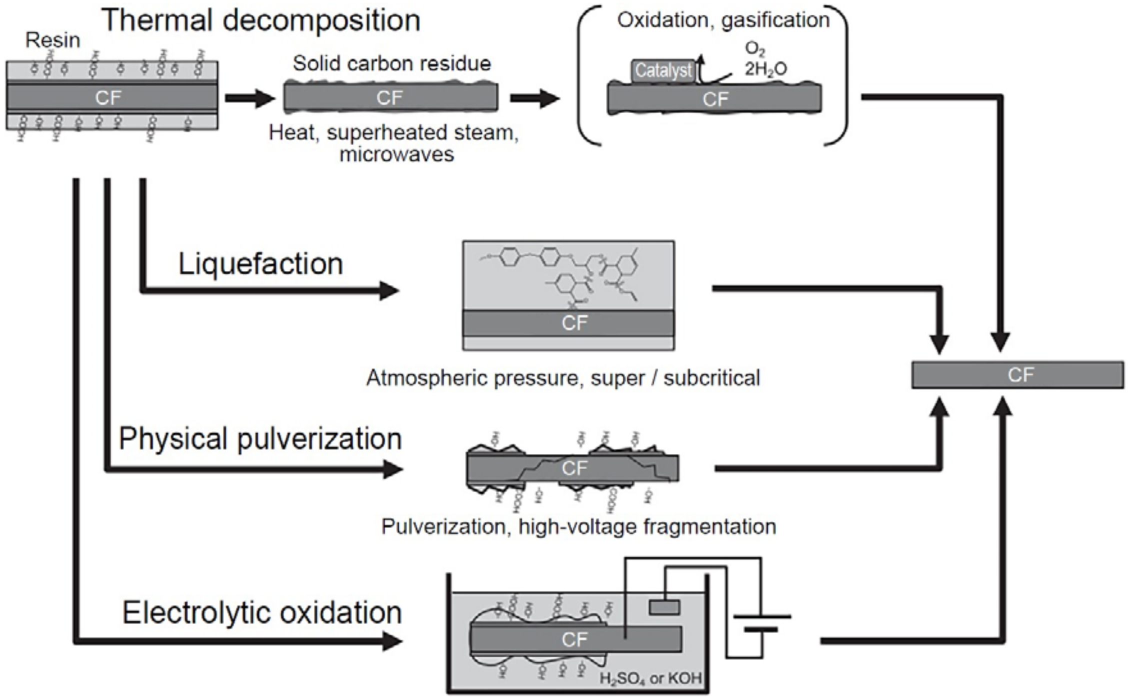
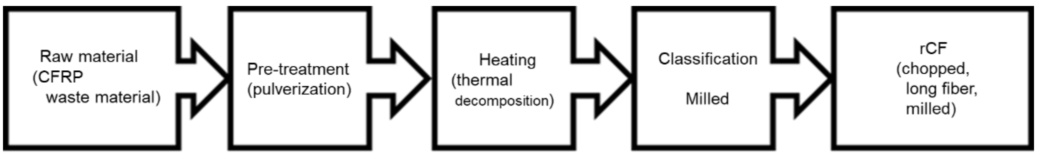
[3]Ministry of Economy, Trade and Industry FY2021 Industrial standardization promotion project consignment fund (Strategic international standardization acceleration project: Survey research on rule formation strategy) "International trend survey on evaluation methods and adoption status of recycled carbon fiber" (March 2022)

An example of a thermal decomposition manufacturing process flow is shown. In the thermal decomposition method, the recovered CFRP waste material is pulverized, and the resin is decomposed and removed at 350–400 ° C, after which the CF is extracted. The shape of the extracted CF is diverse, including long fibers and those that are chopped or milled. By effectively utilizing the waste heat generated in the thermal decomposition process, it is possible to regenerate CFs with low CO_2 emissions of one-eighth to one-seventh that of virgin CF.



(Source) Material Cycles and Waste Management Research, Vol. 29, No. 2, pp. 133–141, 2018

Table/Figure 29. Overview of manufacturing technology for recycled CF

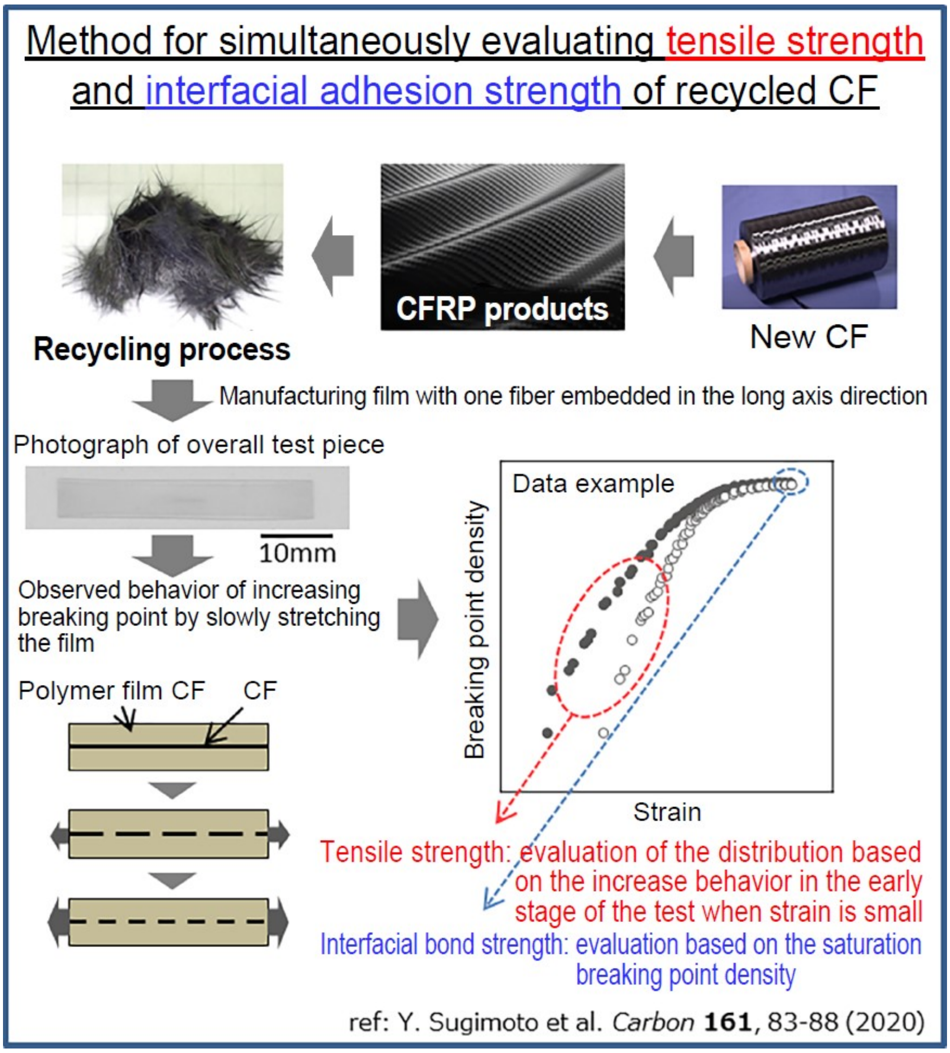


Table/Figure 30. Overview of thermal decomposition method

③ Test standards for recycled CF

CFRP performance is considerably affected by the performance of the CF itself, which is the raw material. The tensile strength of recycled CFs varies considerably depending on the regeneration conditions; thus, there is a need for a method that can accurately evaluate the quality of recycled CFs.

Most of the JIS and ISO test standards are related to CFs and CFRP target continuous fibers, and they are difficult to apply to recycled CFs, which contain multiple discontinuous fibers. It is our hope that CF researchers, users, and manufacturers will work together to form a project for formulating test standards for recycled CFs.



Table/Figure 31. Evaluation method for recycled CFs (example)

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④ Efforts with user industries

Although the use of CFRP parts is limited in the automobile industry, their introduction is expected to be promoted in the future because of weight reduction needs.

In applying CFRP to automobiles and based on the need to establish a disposal method in line with the Act on Recycling of End-of-Life Automobiles, in FY2019–2021, the Carbon Fiber Manufacturers Association participated in the Appropriate CFRP Processing Research Consortium[4] together with the Japan Automobile Manufacturers Association, which is a user group. We investigated the appropriate conditions for the thermal recycling of CFRP as a project of the Japan Foundation for Advanced Auto Recycling (J-FAR).

CF, which is the raw material of CFRP, is a material that has both flame resistance and conductivity. In one example, when an end-of-life automobile equipped with CFRP parts became automobile shredder residue (ASR), there was the incident in which the inclusion of CFRP in the ASR caused problems with the processing equipment of the ASR processing facility. Although it has not been clearly identified that CFs are the cause, there have been requests from processing facilities for information on how to deal with CF contamination and its combustion methods.

Given these circumstances, it was determined to be important to establish thermal recycling technologies before the full-scale use of CFRP parts in automobiles, and the basic combustion characteristics of CF and CFRP were determined to establish appropriate CFRP processing methods. Simultaneously, demonstration experiments were conducted based on the determination of these basic combustion characteristics, and the direction of combustion treatment in existing combustion processing facilities was set.

Additionally, preparations for simulated ASR combustion samples were advanced, and a demonstration furnace was designed and manufactured for the demonstration study. As a result, 97% combustion was achieved in the combustion of CFRP using the demonstration furnace by re-injecting the combustion residue.

In this research project, it was demonstrated that CF and CFRP could be thermally recycled by adjusting the combustion method. Please refer to the following for the details.

[4] Members include the Yano Research Institute, which is the project contractor, as well as the JFE Techno-Research Corporation, Toray Research Center, Japan Automobile Manufacturers Association, and the Japan Carbon Fiber Manufacturers Association Committee of the Japan Chemical Fibers Association.

Japan Foundation for Advanced Auto Recycling (J-FAR)
FY2021 Independent research related to surveys, research, demonstrations, etc. that contributes to the advancement of automobile recycling
“Appropriate CFRP Treatment Research” Final Report
March 31, 2022, Yano Research Institute
https://j-far.or.jp/project/#j

V. Technological innovation efforts (introduction of national projects, etc.)

Various national projects have been launched to develop the basic technologies for energy-conserving manufacturing processes of CF and CF composite materials as well as molding in short periods of time. Each member company of the Carbon Fiber Manufacturers Association actively participates in these national projects and plays a part in the development of basic technologies.

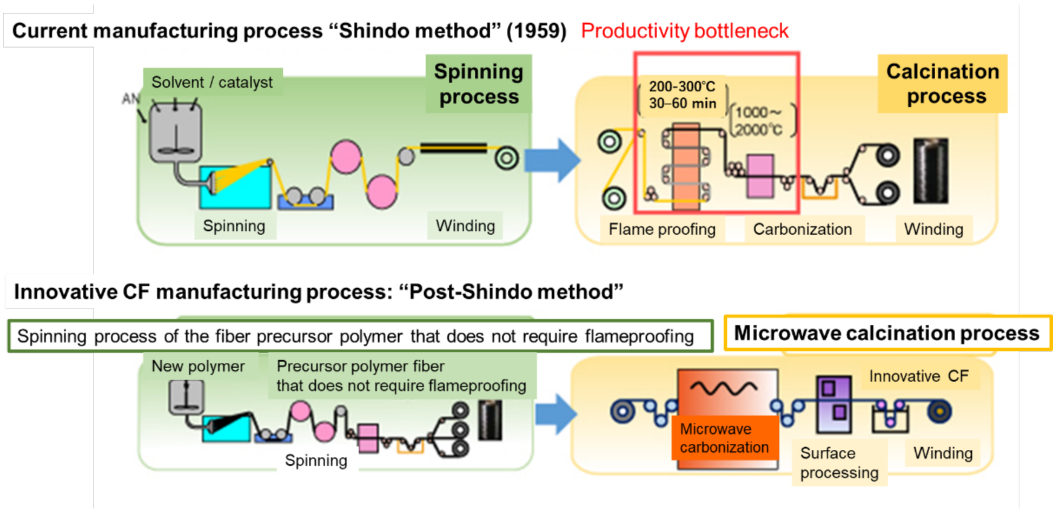
1. Development of innovative CF basic technologies (Innovative Structural Materials Association (ISMA))

A complete overhaul of the current manufacturing method of PAN-based CFs was completed, where the acrylic fibers were made flame resistant at several hundred degrees in air and then carbonized (calcined) at high temperature in nitrogen. The aim was to establish a basic technology for energy conservation and highly productive manufacturing processes.

To eliminate the flameproofing process, which is a bottleneck for improving productivity, a solvent-soluble flame-resistant polymer was successfully synthesized for the first time, and a basic spinning technology for 6K filaments was established. A CF (single thread diameter of 5 μm) made from this precursor as a raw material achieved an elastic modulus of 240 GPa and elongation of 1.5%.

Meanwhile, microwave carbonization technology achieved high-speed carbonization in seconds. Furthermore, a new method to quantitatively and precisely evaluate differences in microwave irradiation conditions, fiber heating mechanisms, and structural changes was found, and the basic technology to achieve stable carbonization was developed.

One future aim is to achieve a single thread diameter of 7 μm, elastic modulus of 240 GPa, strength of 4GPa, and the completion of an industrialized process technology for a large tow (48 K).



Table/Figure 32. Comparison between the current CF manufacturing process (PAN-based) and innovative CF manufacturing process (from ISMA website)

2. Sustainable hypercomposite technology

(New Energy and Industrial Technology Development Organization (NEDO))

The following aims are outlined: develop an intermediate base material that can be molded in a short time using CF and thermoplastic resin, high-speed molding technology, bonding technology, and recycling technology as basic technologies for realizing easy processing and high strengths for CF composite materials; build an advanced energy-conserving society by further reducing the weight of automobiles and considerably improving fuel consumption; and improve the international competitiveness of the Japanese manufacturing industry.

① Development of an intermediate base material of an easy-to-process CF thermoplastic resin composite (RTP)

CF surface processing technologies that achieve both high adhesion with a thermoplastic resin, fiber dispersibility, and impregnation process passability, thermoplastic resins that achieve both impregnation into CFs and physical properties, and isotropic/unidirectional CFRTP intermediate base materials with excellent productivity and workability into parts have been developed.

② Development of molding technology for easy-to-process CFRTPs

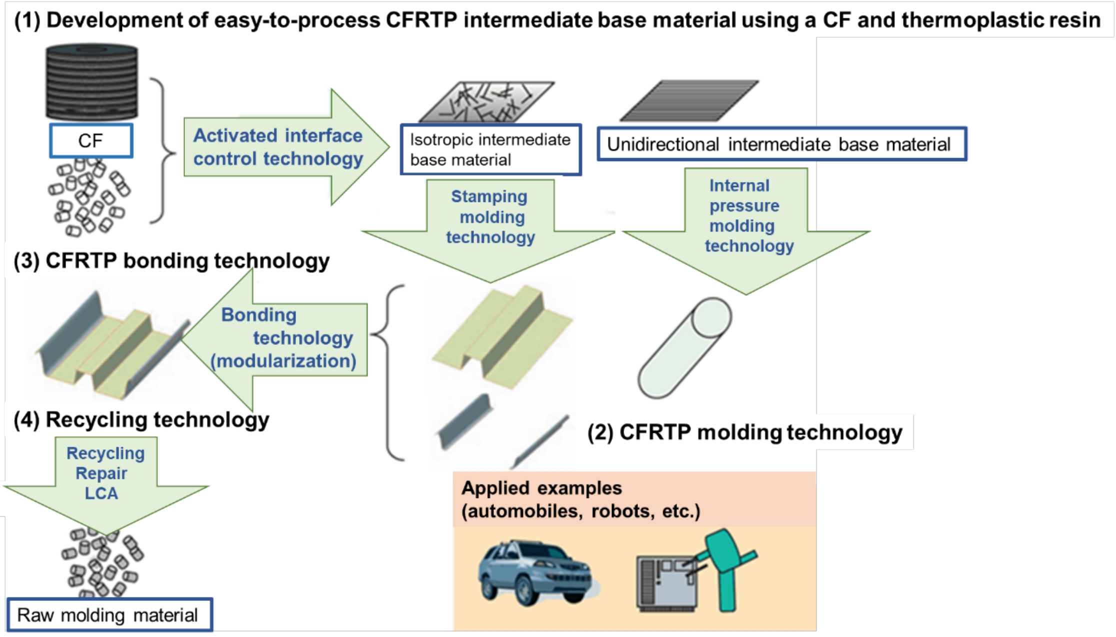
High-speed stamping molding technologies and high-speed internal pressure molding technologies will be developed as high-speed molding technologies that use the CFRTP intermediate base material.

③ Development of bonding technology for easy-to-process CFRTPs

High-speed bonding methods with sufficient bonding strength will be developed by various bonding types for various CFRTP components developed via the research and development items ① and ②.

④ Development of recycling technology for easy-to-process CFRTP

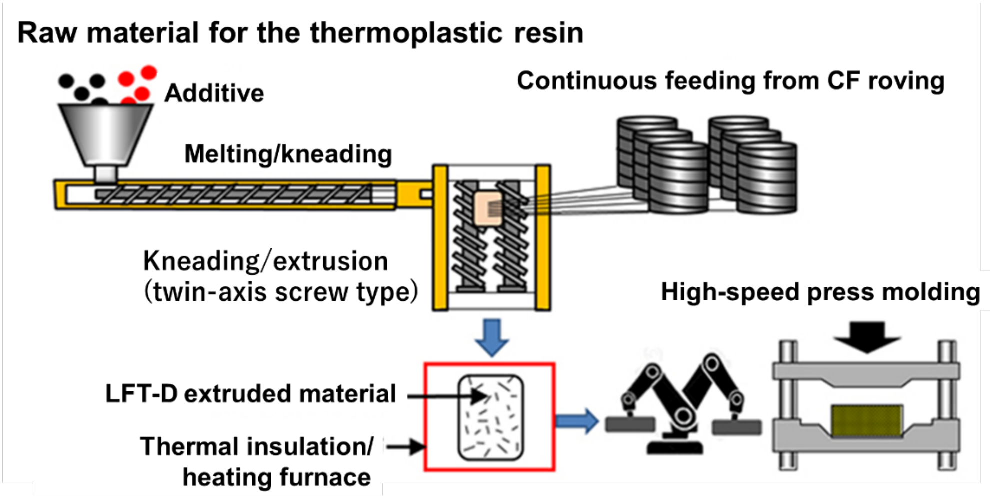
Technologies that improve recyclability (performance retention rate after recycling, number of recyclable times) and repair technologies will be developed for various CFRTP components developed via the research and development items ①, ②, and ③. Additionally, an environmental impact assessment (LCA) will be conducted to quantify the degree of contribution to reducing the environmental impact when this developed technology is used in various products.



Table/Figure 33. New Energy and Industrial Technology Development Organization (NEDO) homepage
From "Development of sustainable hypercomposite technology"

3. National Composite Center (NCC)

CFRP is a material that is expected to reduce CO_2 emissions by reducing the weights of automobile bodies. However, although general thermosetting CFRP has excellent mechanical properties, it has issues, such as a long molding time, and its application has been limited to aircraft and some luxury automobiles. Therefore, by focusing on thermoplastic CFRP, which has excellent moldability and adhesion, and by applying the long-fiber thermoplastic direct (LFT-D) method, automobile chassis parts could be molded in approximately one minute. Furthermore, chassis assembly technology that uses the ultrasonic fusion method has been used to successfully manufacture an automobile chassis (10% lighter than the current aluminum chassis) made entirely of thermoplastic CFRP for the first time in the world.



Table/Figure 34. Conceptual diagram of the LFT-D fabrication method (from the ISMA website)

Table/Figure 35. Thermoplastic CFRP prototype chassis (from ISMA website)

4. Strategic Innovation Promotion Program (SIP) "Structural Materials for Innovation"

(Japan Science and Technology Agency (JST))

The essential requirements for advanced structural materials used in commercial aircraft airframes and engines are that they have a low weight, low cost, high quality, and excellent productivity and maintainability. CFRP was selected for the airframe, heat-resistant metals and ceramics were selected for the engine, and technical issues, including those related to material development, process/processing technology, and structural design technology, were selected.

Research domain A: Development of aircraft resins and CFRPs

- Development of materials and their manufacturing technologies that achieve high quality, low cost, and high productivity of main structural components (tails, wings, etc.) that can replace the existing autoclave method and development of a low-cost, high-quality (strong) autoclave prepreg for application to main structural components (main wings, etc.)
- Development of a thermoplastic prepreg with excellent impact resistance and heat resistance for aircraft engine parts and molding technology and achievement of weight reduction by developing application technologies for heat-resistant polymer matrix composite material（PMC）.
- Molding process monitoring of composite structures, quality assurance technologies, non-contact/non-destructive inspection technologies, and bonding technologies

Research domain B: Development of heat-resistant alloys and intermetallic compounds

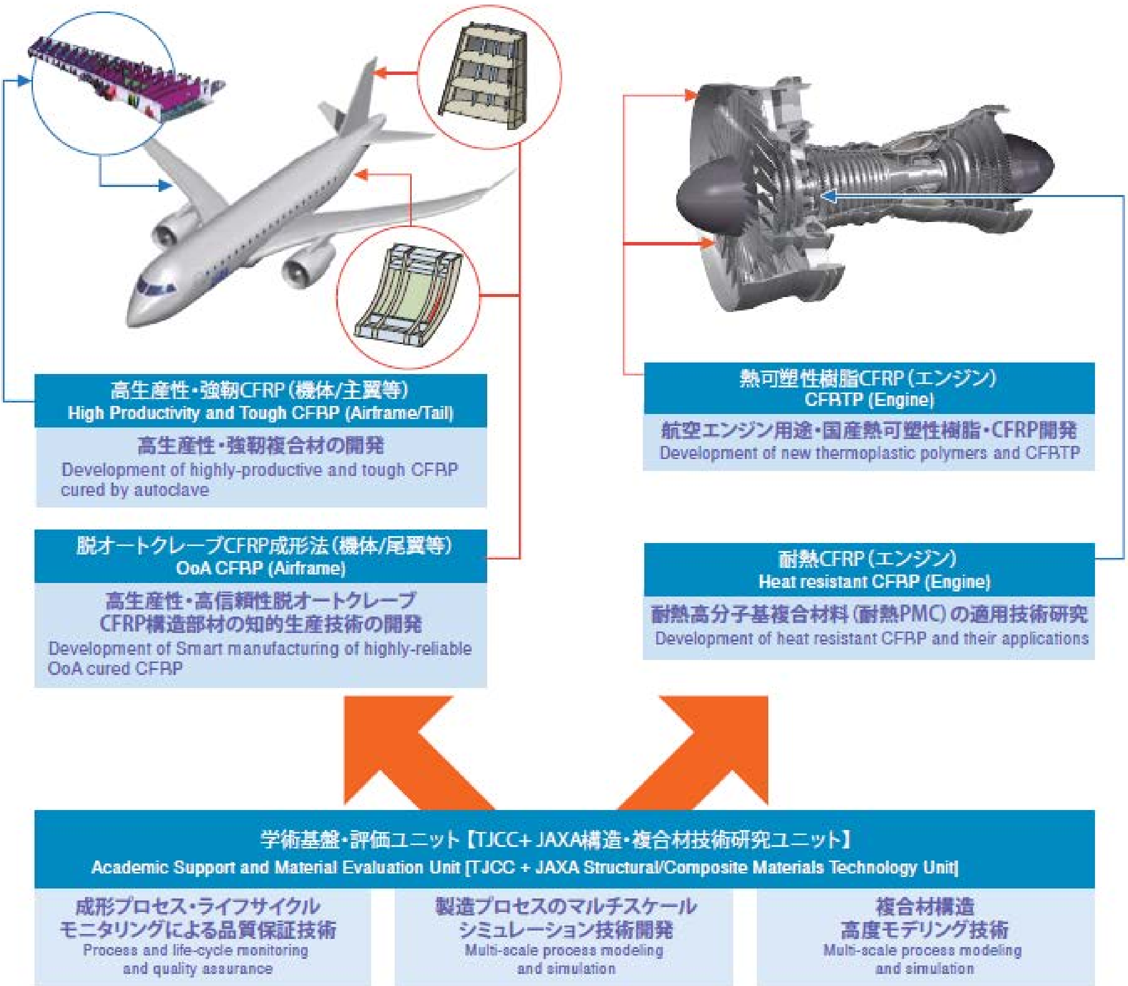
- Innovative large-scale and practical forging technologies for Ti alloys and Ni-based alloys, which are the main materials for aircraft engines and power generation turbines, and development of simulation technologies and database development to support these technologies
- Development of laser powder cladding technologies with excellent workability and productivity, as well as injection molding technologies with excellent dimensional accuracy and fatigue resistance, for application in aircraft and turbine components

Research domain C: Development of ceramic matrix composites

- Practical application of heat-resistant and lightweight ceramic components is expected to considerably improve fuel consumption and reduce CO_2

emissions of aircraft engines via the development of environmentally resistant coating technologies that protect the surface of these components from high-temperature oxygen and steam environments and that enable long-term use.

- Development of environment-resistant coating technologies that can be applied to lightweight ceramic components that have both high toughness and heat resistance



Table/Figure 36. Development of the Strategic Innovation Promotion Program (SIP) “Structural Materials for Innovation”
(From the SIP “Structural Materials for Innovation” pamphlet)

VI. Proposal to the government for low-carbonization of CFs (reduce CO_2 emissions)

Measures to reduce CO_2 emissions from CFs and achieve carbon neutrality pose multiple challenges that are difficult for the CF industry alone to tackle. Requests to the government are summarized below.

① Support for low-carbon technology development

- Support for the introduction of equipment that contributes to low-carbonization/decarbonization (in-house power generation equipment, renewable energy equipment, innovative energy conservation/CO_2 emission reduction equipment)
- Early establishment of power generation technology that can be implemented using decarbonized fuels (using hydrogen, ammonia, bio-derived fuels, etc.)
- Development and social implementation of manufacturing technologies of bio-derived raw materials and early technologies, such as CCS/CCU

② Development of a mechanism to continually promote low carbonization

- Various types of support for the development of CF recycling businesses (collection of CFRP waste materials, quality assessment of recycled CF, development of applications, etc.)
- Development of an internationally consistent mechanism in which society as a whole bears the costs of fuel conversion, etc.

③ Stable and cheap supply of decarbonized energy

- Achievement of zero emissions by 2050 for electric power supplied from electric power companies

VII. Conclusion

This vision includes the activities conducted to date by the Japan Carbon Fiber Manufacturers Association Committee (formerly Carbon Fiber Manufacturers Association) of the Japan Chemical Fibers Association and a summary of the contributions CFs can provide even in a carbon-neutral society by formulating visions for the future of 2030 and 2050.

CF is still called an innovative material half a century after its birth because it constantly provides new value to the products that use it. CF has the power to change society via its multiple excellent performances, such as weight reduction and high rigidity, which can be imparted to products. It also plays a role as a material that protects the environment of the planet.

In a carbon-neutral society, conventional efforts needed as well as further efforts, such as countermeasures against CO_2 generated at the manufacturing stage. Expectations are focused on not only fuel conversion in the CF manufacturing process but also the realization of a resource recycling (CF recycling) system, which should be promoted in combination with the user industry, and the introduction of technology to cheaply absorb and re-use reaction-derived CO_2, which is difficult to completely eliminate.

We would like to ask for the continued understanding and support of the involved parties.

End

Reference materials

1. CF LCI data

The most recent LCI data for virgin CFs compiled by the Carbon Fiber Manufacturers Association (based on FY2017 production results of three PAN-based CF manufacturers) and LCI data for recycled CFs compiled by the Carbon Fiber Recycling Technology Development Association (collected at Omuta Pilot Plant) are shown in Fig. 37.

	Feedstock Energy (MJ/kg)	Energy consumption (MJ/kg)	CO_2 emission (kg CO_2/kg CF)
Virgin CF	32	319	19.8
Recycled CF	−	4 6	2.6

(Note) Feedstock energy: combustion heat not used as an energy source from the input of raw materials to the product system

Table/Figure 37. LCI data for virgin and recycled CFs

2. Major domestic and international CFRP recycling commercialization companies and research institutions

Country	Company name / Organization name		Recycling method	Processing capacity(2019)	Pre-processing	Temperature / Pressure	Solvent	Catalyst	Recycled product form
Japan	Manufacturer	Ai-Carbon	Thermal decomposition	Unknown	Pulverization	400–500°C	Unnecessary	Unnecessary	Cf (dry-type non-woven fabric (approximately 50 mm in size), fiber for injection molding pellets and concrete reinforcement (3–6 mm))
			Electrolytic oxidation	Unknown	Pulverization	Normal temperature/normal pressure	Concentrated nitric acid, alkali	Unknown	CF (slurry)
		Earth Recycle	Electrolytic oxidation	20 t/y	None	275°C/normal pressure	Glycol solvent	Alkali metal salt	CF (chopped, milled, long fiber)
		Whisca	Thermal decomposition	Unknown	Pulverization	Unknown	Unnecessary	Unnecessary	CF (milled)
		ACA	Pulverization/dispersion by air flow	Unknown	Pulverization	Unknown	Unnecessary	Unnecessary	CF (milled)
		CF Recycle Industry	Thermal decomposition (two-stage heating)	3,000 t/y	Unnecessary	500–550°C	Unnecessary	Unnecessary	CF (chopped, milled, long fiber)
		Shinryo	Thermal decomposition (superheated steam)	200 t/y	Cutting	600°C	Unnecessary	Unnecessary	Compound product with thermoplastic resin
		Takayasu	Thermal decomposition	Approx. 60 t/y	Unknown	Unknown	Unnecessary	Unnecessary	Non-woven fabric
		Fuji Design	Thermal decomposition (hot air circulation)	360 t/y	Cutting	400–480°C	Unnecessary	Unnecessary	Compound product with thermoplastic resin
	Research institution	JAXA Aviation Technology Directorate	Solvolysis	-	Cutting (10–50 mm²)	Normal temperature/normal pressure	Unknown	Unknown	CF (short fiber)
		Saitama Industrial Technology Center	Solvolysis	-	Unknown	Normal temperature/normal pressure	HCl-BZA solvent	Unknown	CF
		Shinshu University	TASC	-	Unknown	500°C	Unnecessary	Unnecessary	CF
		Japan Fine Ceramics Center	Thermal decomposition (superheated steam)	60 t/y	Cutting	500°C	Unnecessary	Unnecessary	CF (recoverable in woven form)

Source: created by Yano Research Institute

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Country	Company name / Organization name		Recycling method	Processing capacity(2019)	Pre-processing	Temperature / Pressure	Solvent	Catalyst	Recycled product form
United States	Manufacturer	Adherent Technologies, Inc.	Thermal decomposition	-	-	500° C	Unknown	Unknown	CF
			Solvolysis	-	-	-	Unnecessary	Unknown	CF
			Chemical process (high-temperature fluid processing)	-	-	Temperature of 300° C or more, pressure of 500 PSI (3.45 MPa)	Unnecessary	Unknown	CF
			Chemical process (low-temperature/low-pressure fluid processing)	-	-	Pressure of 150 PSI, temperature of 150° C	Unnecessary	Unknown	CF
		Carbon Conversions, Inc. (formerly: MIT-RCF. LLC)	Thermal decomposition	2,500 t/y	Pulverization	Normal pressure	Unnecessary	Unknown	CF (chopped, LFT pellets, non-woven fabric, short fiber mat roll)
		CF Remanufacturing (AdTech International, Inc.)	CF production process recycling	240 t/y	-	-	Unnecessary	Unknown	CF
		Composite Recycling Technology Center(CRTC)	Other	-	-	-	Unnecessary	Unknown	CF
		Firebird Advanced Materials	Microwave	-	-	-	Unnecessary	Unknown	CF
		Shocker Composites	Solvolysis	-	-	-	Unnecessary	Unknown	CF
		Vartega	Solvolysis	-	-	-	Unnecessary	Unknown	CF (chopped, LFT pellets, non-woven fabric)
			Supercritical fluid	-	-	-	Unnecessary	Unknown	

Source: created by Yano Research Institute

Preriminary

Country	Company name / Organization name		Recycling method	Processing capacity (2019)	Pre-processing	Temperature / Pressure	Solvent	Catalyst	Recycled product form
United States	Research institution	ACMA-IACMI-CHZ Technologies	Thermal decomposition	-	-	-	Unnecessary	Unknown	CF
		Georgia Institute of Technology, Atlanta	Alcohol decomposition	-	-	160–180°C	Unnecessary	Unknown	CF
		Global Fiberglass Solutions/Washington State University	Solvolysis	-	-	-	Unnecessary	Methanol , ethane	CF
		Mallinda/University Colorado Boulder	Polyimine application	-	-	-	Unnecessary	Polyimine	CF
		North Carolina State University	Unknown	-	-	-	Unnecessary	Unknown	CF
		Triumph Composites Systems/Washington State University	Unknown	-	-	-	Unnecessary	Unknown	CF
		University of Southern California	Alkaline digestion/oxidative digestion	-	-	-	Unnecessary	Unknown	CF
		Washington State University	Supercritical fluid method	-	-	Temperature of 80–250°C	Unknown	Potassium hydroxi	CF

Source: created by Yano Research Institute

Preriminary

Country	Company name / Organization name		Recycling method	Processing capacity (2019)	Pre-processing	Temperature / Pressure	Solvent	Catalyst	Recycled product form
Germany	Manufacturer	Mitsubishi Chemical Advanced Materials (formerly: carboNXT or CFK Valley Stade Recycling)	Thermal decomposition	-	None	gaseous decomposition	Unnecessary	Unknown	CF (milled, chopped, fiber ball, fiber tube, rCF compound, non-woven fabric, Veil, rCF smc/rCF bmc)
		HADEG Recycling GmbH	Thermal decomposition	-	-	-	Unnecessary	Unknown	CF (short fiber, rCF compound, sheet)
		SGL Carbon	Thermal decomposition	-	-	-	Unnecessary	Unknown	CF (non-woven fabric)
	Research Institution	Fraunhofer (IGCV, ICT, IVV)	Thermal decomposition by microwaves	-	-	-	Unnecessary	Unknown	CF
		Hohenstein Institute, MAI Carbon	Decomposition by micro-organisms	-	-	-	Unnecessary	Unknown	CF
		RWTH Aachen University	Thermal decomposition	-	-	600° C or more	Unnecessary	Unknown	CF
United Kingdom	Manufacturer	ELG CF (formerly Recycled Carbon	Thermal decomposition	-	Cutting	600–900° C	Unnecessary	Unknown	CF (tow, milled, chopped, pellet)
		Hexcel Reinforcements UK Limited	CF production process recycling	-	-	-	Unnecessary	Unknown	CF
		Sigmatex	CF production process recycling	-	-	-	Unnecessary	Unknown	CF
	Research Institution	Cranfield University	Solvolysis	-	-	-	Unnecessary	Unknown	CF
		Imperial College London	Thermal decomposition	-	-	-	Unnecessary	Unknown	CF
		University of Birmingham	Thermal decomposition, solvolysis	-	-	-	Unnecessary	Unknown	CF
		University of Bristol	Thermal decomposition	-	-	-	Unnecessary	Unknown	CF
		University of	Chemical process	-	-	-	Unnecessary	Unknown	CF
		University of Nottingham	Fluid bed treatment	-	-	450–550° C	Unnecessary	Unknown	CF
			Supercritical fluid method	-	-	-	Unnecessary	Unknown	CF
France	Manufacturer	Vetrotex	Solvent wash method	-	-	-	Unnecessary	Unknown	CF
	Research institution	Alpha Recyclage	Steam-based thermal decomposition	-	-	Heating with water vapor	Unnecessary	Unknown	CF
		I2M Laboratory	Supercritical water solvolysis method	-	-	-	Unnecessary	Unknown	CF
Italy	Manufacturer	KARBOREK Recycled Carbon Fibres	Thermal decomposition	-	-	Heat treatment of waste CFRP in reactive	Unnecessary	Unknown	CF (milled, chopped, felt)

(Source) Ministry of Economy, Trade and Industry FY2020 Global warming and resource recycling countermeasures survey consignment fund “International trend survey on the use and evaluation methods of recycled carbon fiber” (March 2021)

Table/Figure 38. Recycling methods implemented by CF recycling companies (manufacturers) and research institutions worldwide

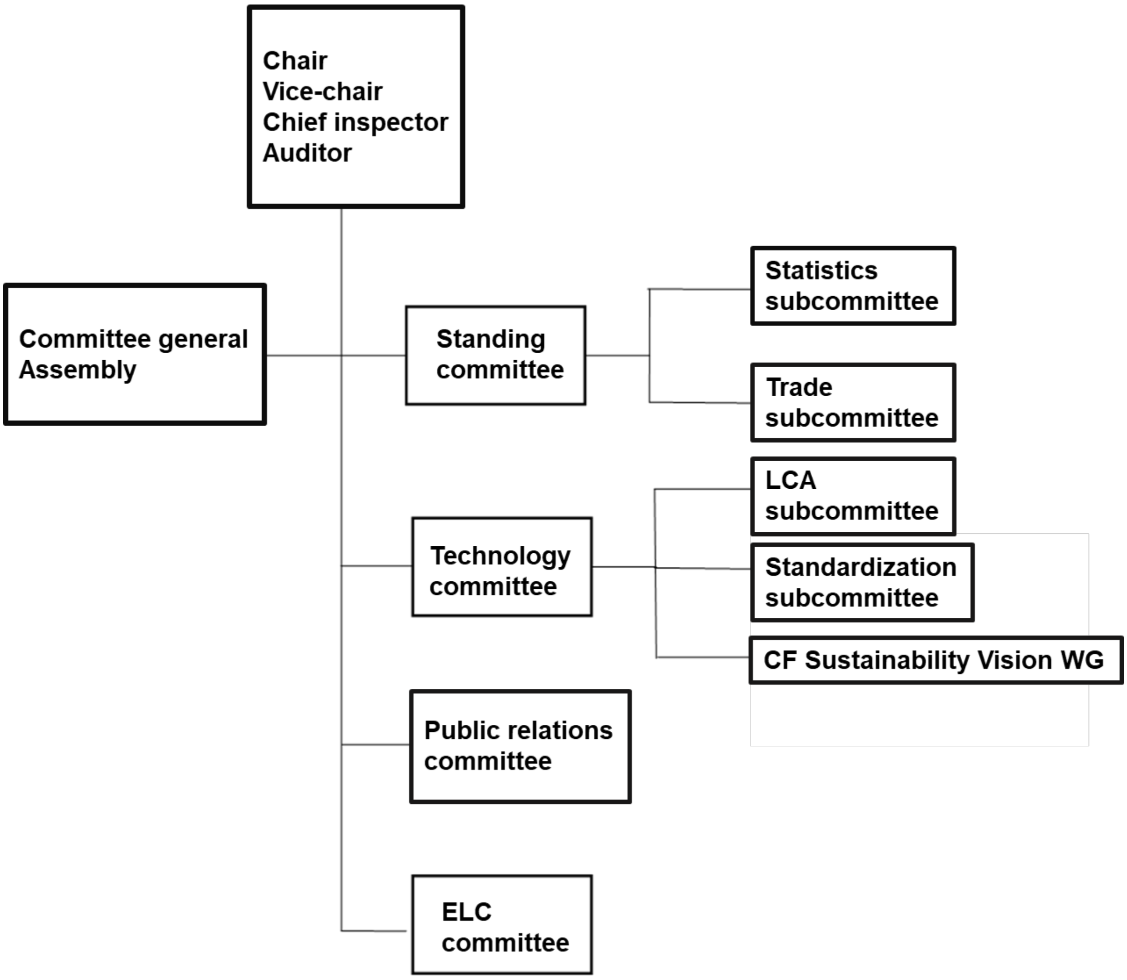
3. Framework for carbon neutrality by the Carbon Fiber Manufacturers Association

The framework and responsibilities for carbon neutrality at the Carbon Fiber Manufacturers Association Committee are summarized below.

Corresponding organization	Content
CF Technology Committee	General technologies related to CF REACH-compliant
CF Sustainability Vision Working Group	Creation, dissemination, and revision of a vision for carbon neutrality in the CF industry
LCA Subcommittee	LCA of CFs LCI data survey Additions and revisions to the Carbon Fiber Manufacturers Association model
Standardization subcommittee	Standardization of recycled CFs Standardization of testing methods for recycled CFs

(Reference) measures by each company	Energy sector measures Manufacturing sector measures Recycling

Table/Figure 39. Framework for carbon neutrality by the Carbon Fiber Manufacturers Association Committee



Table/Figure 40. Organizational chart of the Japan Carbon Fiber Manufacturers Association Committee, Japan Chemical Fibers Association