Overview of LCI data for carbon fiber

October 2022

The Japan Carbon Fiber Manufacturers Association

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1. Methods and purpose

The analyses were performed according to ISO14040 and ISO14044. The ISO14044 shows four steps, i.e., "the goal and scope definition", "the inventory analysis", "the impact assessment", and "the interpretation", but since the main objective of this survey is to conduct an inventory analysis of carbon fiber, "the impact assessment" and "the interpretation" were not conducted. However, the results of the inventory analysis itself are described in the section describing the results, and include some interpretation of the inventory analysis results. The survey was conducted under contract with Industry Information Collaboration Research Center (WIC), which has conducted numerous inventory analyses for the materials industry.

1-1 Reason for this survey

Since The Japan Carbon Fiber Manufacturers Association (JCMA) constructed its first LCI model of PAN-based CF in the fiscal year 1997 (the first survey), it has carried out several updates of LCI data as fixed point observation in fiscal years 2004, 2006, and 2012. During this period, data updating based on **actual production data** has been carried out since fiscal year 2006. This analysis is an update of the data of fiscal year 2012.

The purpose is to construct data based on the most recent production results as far as possible, to prepare information as LCI data for the product concerned, and at the same time to extract the improved points of the methods and reports and reflect at the time of next renewal.

1-2 Intended use

In addition to providing basic data to identify the environmental position of the product as a producer, the data will be disclosed and used to improve the technology of the individual companies, and at the same time, the latest information on the environment of the product will be widely disseminated.

1-3 Target of this report

This report is intended for the people involved in the production of the product, Japanese and foreign consumers of the product, researchers at universities and public research institutions, and anyone else interested in the environmental characteristics of the product.

1-4 Presence or absence of comparative claims

No comparative claims are made.

2. Abbreviation

In this report, the following abbreviations are used for chemical substances or manufacturing processes:

Table 1 Abbreviations used in the report.

Substance name or manufacturing process name	Abbreviation
Acrylonitrile	AN
Polyacrylonitrile	PAN
Precursor	PC
Carbon fiber	CF
Propylene oxide	PO
Propylene glycol	PG
Epoxy	EP
Polyacrylonitrile (PAN) manufacturing process	Polymerization process
Precursor (PC) manufacturing process	Spinning process
Carbon fiber (CF) manufacturing process including the oxidation process for flame-proofing	Carbonization process

3. Data quality

The information on the data quality was divided into the foreground data and the background data in the following.

3-1 Foreground data

(1) Time-related coverage

Data based on the actual production data for 12 months of 2017 (fiscal or calendar year) were collected.

(2) Geographical coverage

The data is production data of plants located in Japan.

(3) Technology coverage

This report covers "high-strength fibers with elastic modulus of 230-250 GPa and filament counts of 12k (800 tex) to 24k (1600 tex)," which constitute the main production varieties of PAN-based CFs. In addition, the responses covered those produced on high-productivity core line facilities that are expected to be the mainstay in the future, considering the most recent level of the technology.

In the past, the main markets for CF were aerospace equipment and military-related products, but it is expected that the market for CF will be developed in the automotive, energy, and general industrial fields in the future. Therefore, it is expected that the capacity of unit production line will expand, and it will be necessary to estimate model data based on the effect of scale and to update the data based on actual results in the future.

(4) Precision

Utility data such as electricity, steam, fuel, and water are reported based on actual production results that are collected and managed during normal operation, and the accuracy of the production process data is judged to be high.

The data for the indirect sector, which covers environmental countermeasure equipment and shared facilities such as offices, is based on the amount that should be borne by the production facilities of the subject product, and thus contains elements of slightly lower accuracy compared to the production process data. However, in order to avoid differences in the assumptions of the data to be answered by different companies, WIC and the companies disclosing data carefully exchanged opinions on the production process, definition of data to be collected, the concept of allocation, etc. before receiving data disclosure. Therefore, it is judged that a high level of data accuracy was also ensured in the indirect sector.

(5) Completeness and representativeness

Although the production volume of the analyzed products does not represent the total production volume of PAN-based CF worldwide, the products considered here form a large part of the CF products and are supplied to major markets of CF, such as aerospace equipment and automotive applications. The data is collected from all the manufacturers of these products based on the same assumption, and it can be said to cover practically the entire production volume of products supplied to the main markets.

In this survey, all processes of CF production were divided into PAN, PC, CF to collect data on each production result basis, and data on annual **6,994 tons** were obtained on a PAN-based CF production basis.

Although the Japanese production volume of PAN-based CF is not disclosed in official statistics, according to the Ministry of Economy, Trade and Industry's Current Production Statistics, the Japanese production volume of CF, including pitch-based CF, was 18,903 tons in fiscal year 2017. Assuming that the production volume of pitch-based fibers is 50% of its production capacity, 1,615 tons is estimated. Thus 17,288 tons of Japanese CF are obtained by subtracting this amount from 18,903 tons, thus assumed to be the Japanese production volume of PAN-based CFs in the same year, the ratio of PAN-based

CFs aggregated in this survey corresponds to about 40% of the Japanese production volume. The data is considered to be representative enough for the major markets for CF, such as aerospace equipment and automobiles.

Inventory data vary greatly not only with the development of new technologies and the conversion of raw materials, but also due to their properties, with operational rates and technological trends in upstream processes. Efforts to conserve energy are also expected to continue in both products due to improvements in production technology and other factors. Therefore, JCMA believes that ideally the data should be updated on a regular basis.

(6) Consistency

All Japanese manufacturers of PAN-based CF participated in this analysis, and upon receiving data disclosure, the disclosing companies and WIC carefully discussed data collection methods and definitions. The data processing method is basically the same as that used to construct LCI data for petrochemical products (polyethylene, polypropylene, polystyrene, styrene foam, vinyl chloride resin, ABS resin, polyamide, polycarbonate, PMMA, main synthetic rubber and all of the main raw materials required for producing these polymeric materials) for which WIC was in charge of data construction. In addition, the coefficients applied to the retrospective calculations of electricity, steam, fuel, etc. are also from the same data source for all companies. Therefore, it is judged that not only the survey methods and data processing methods but also the calculation contents are sufficiently consistent.

(7) Critical Review

External reviews were carried out with the request of three knowledgeable persons who were familiar with LCA.

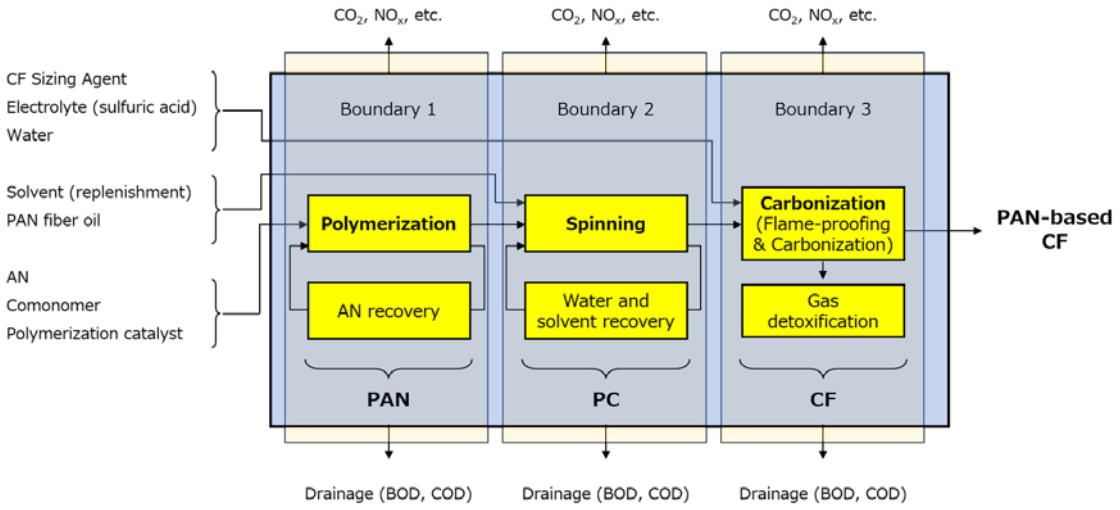
3-2 Background data

Background data cannot be uniformly described in terms of data quality because the data source varies depending on the data applied. Therefore, we have organized the data year and data creators (or names of references cited) in the list of data used (Table 5), which is described below. The table also includes foreground data.

4. System boundary

4-1 Manufacturing process for PAN-based CFs

Figure 1 shows the manufacturing process of PAN-based CF. The manufacturing process consists of three steps: polymerization, spinning, and carbonization, and data were collected separately for each step. However, in some cases, it was difficult to divide the data by manufacturer, and the decision was left to the judgment of the individual company disclosing the data. As a result, there was a case in which the data was disclosed in two parts: "polymerization process to spinning process" and "carbonization process," and the data was compiled accordingly.



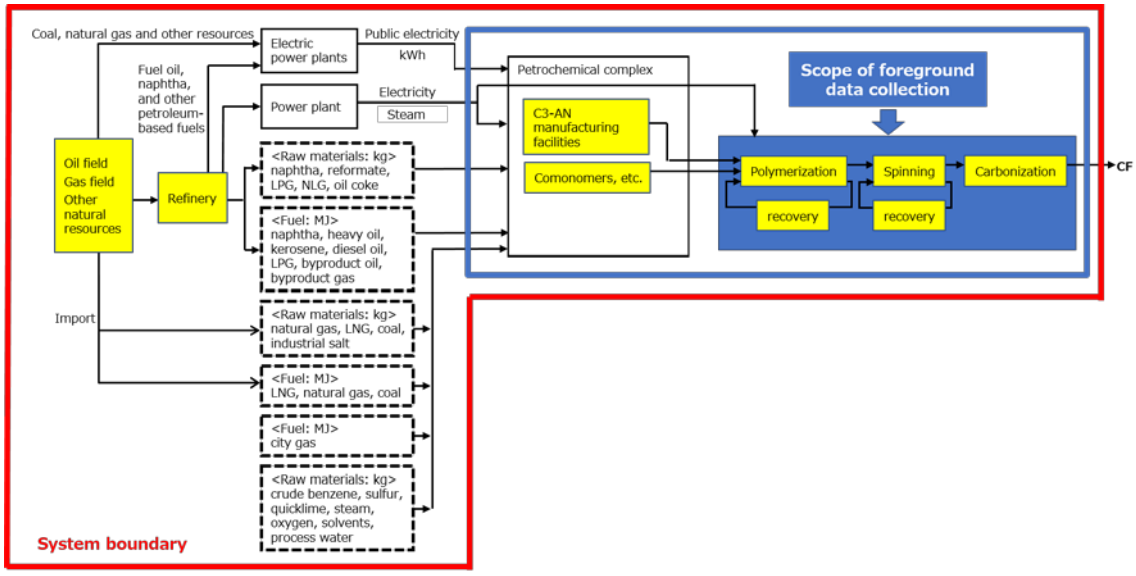
Note 1: LPG (Liquefied Petroleum Gas) input for detoxification of flue gas is not shown here because it is different from treatment agent.

Note 2: The environmental impact of combustion associated with the use of electricity, steam, and fuel is not shown here.

Figure 1 Manufacturing process of PAN-based CF.

4-2 System boundary and survey scope (computational scope)

Figure 2 shows the scope of the calculations for this analysis and the system boundaries of the PAN-based CF for which foreground data are collected. In the figure, the polymerization - spinning - carbonization area is the set system boundary, and the area enclosed by the solid red frame is the scope of the overall calculation.



Note: Data was collected for each process (polymerization, spinning, and carbonization), and an inventory analysis was conducted for each process. After weighting and averaging the results of each company's inventory analysis for each of the three processes by the ratio of each production volume, LCI data for the three processes were calculated as a single unit.

Figure 2 Computational scope of inventory data and system boundaries of PAN-based CF.

5. About data

5-1 Data item

The items of collected data of this analysis are roughly divided into foreground data and background data. In the foreground data, a series of processes composed of polymerization process, spinning process, and carbonization process were assumed to be CF manufacturing process, and the input and production, utility, and environmental releasing substances were made to be the object items of data collection. Among them, items related to input, production, and utilities are shown in Table 2, and substances released into the environment are shown in Table 3, respectively.

Table 2　Survey items of CF manufacturing process.

Input raw materials	Produced products	Utilities
Acrylonitrile (AN)	PAN-based carbon fiber	Electricity Consumption
Comonomer		Steam Consumption
Polymerization catalyst		Fuel consumption
Solvent		Utility gas (nitrogen)
PAN fiber oil (PG)		Water consumption
Carbon fiber sizing agent		
Electrolyte (sulfuric acid)		
* Packaging film (PE)		
* Paper tube		
* Outer packaging material		

Note 1: Items marked with an asterisk (*) were excluded from the retrospective calculation. PE film and corrugated cardboard are used for the outer packaging materials depending on the process.

Note 2: Oxygen is used in the carbonization process, but it is taken in by air, so oxygen is not included in the utility items. The electricity consumed when taking in air was reported as process electricity consumption.

Table 3　Survey items of environmentally hazardous substances

Atmospheric emissions	Wastewater system emissions	Solid waste
soot and dust	COD	Waste plastic
SO_x	BOD	Waste oil
NO_x	SS	Waste acid (after dehydration)
HC (hydro carbon)	Oil	Waste alkali (after dehydration)
CO (as CO)	Phenols	Sludge (organic) - dry
CO_2 (as CO_2)	Phosphorus compounds	Sludge (inorganic) - dry
CH_4	Nitrogen compounds	Cinders (including fly ash)
HFC		
PFC		
N_2O		
SF_6		
Cl_2		
HCl		

Among the utilities listed in Table 2, foreground data was collected for on-site power generation and steam, and the actual results of the power plants in factories where the CF manufacturing process of the data disclosing company in operational were taken as the items to be investigated. Environmental countermeasure equipment was included in the responses the participating companies provided, including energy consumption

and environmental releases that are considered to be borne by the unit process.

Data related to utilities such as industrial water and nitrogen, public power, data related to the production of various petroleum-based fuels, etc. (data on petroleum refining), and data related to the mining and extraction of crude oil and transportation associated with the import of these fuels were all considered to be background data, and they were included in the data collection. Specifically, data on public power, petroleum refining, mining and extraction of crude oil and coal (fuels), and transportation associated with the import of these fuels were obtained through the use of official statistics and data prepared by the industries concerned.

Among the items described as background data in this report, utility data such as water and nitrogen should be positioned as foreground data, and actual data of companies disclosing data on the relevant unit processes should be collected at the same time. In this analysis, actual data were collected for the amount used, but background data were used for the production of these items. However, for water use, the power consumption during pumping and transfer associated with water use was reported as process power consumption, and as a result, actual data was collected. In this case, responses were obtained separately for public power and on-site power generation.

5-2 Assumptions for data collection

In this section, the assumptions for the collected data of this analysis (principles at the data collection stage, pre-arrangements in response) are described by dividing them into (1) input raw materials, (2) produced products, (3) energy consumption, and (4) environmental impact data.

(1) Input raw materials

i) All raw material inputs were assumed to be as is.

ii) The amount of raw materials recovered and recycled in the system was assumed to be the replenishment amount, based on the assumption that the recycling use is regularized and that energy, etc. associated with recovery are included in the energy input.

iii) However, the amount of AN recovered in the polymerization process is very small compared to the amount of AN that is converted to PAN and then to CF. The main line is the process of converting AN to CF, and the AN from that process is actually recovered to the best extent possible so that it is not dumped out of the system. As

a result, AN contains a mixture of recovered and newly added amounts, and although the new input amount can be considered as a replenishment amount, it has a different nuance from the usual in-system recycling.

iv) Electricity for water withdrawal, drainage, and transfer associated with the use of water is included in the process electricity consumption. All water for irrigation, including rivers, lakes, seawater, groundwater (wells), and industrial water purchased from municipalities, were included in the scope of this study. However, energy consumption and environmental impact of water conversion were calculated for degassed water among industrial water, pure water, and boiler water purchased from municipalities, but background data was used for the unit data (not calculated in the previous case).

v) All nitrogen is purchased nitrogen. Background data was used to calculate the amount of electricity and steam consumed in obtaining nitrogen. Background data was also used to calculate the energy consumption and environmental emissions associated with this power and steam consumption (both data were from the petrochemical industry).

vi) Since all oxygen used in the carbonization process is taken from the air and the oxygen in the air is used, the power consumption associated with the air intake was tabulated and included in the calculations in this analysis. The same power consumption was to be reported as process power consumption.

(2) Produced products

i) As for the produced products, the quantity of CF as a final product was the target of data collection, and the quantity of PAN and PC as intermediate raw materials was not included.

ii) The valuable off-grade PC and CF were separately collected as by-products, and were included in the allocation of energy consumption and environmental impact in the calculation of LCI data.

iii) For items such as solvents that are recovered and recycled for use in the system, the amount of recovery was deducted from the amount of input and the amount of replenishment was used as the data item to be collected, assuming that this is a regular practice and that the energy and environmental impact associated with recovery and recycling processes are included in the calculation. The energy consumption associated with recovery was included in the energy consumed by the process, such as electricity, steam, and fuel.

(3) Energy consumption

1) Electricity

i) Electricity was divided into two categories: Electricity received from the on-site power generation plant and so-called purchased electricity (public electricity), and data were collected separately.

ii) Electricity consumed for intake, transfer, and post-use drainage of water used in the plant was included in the data collected as process electricity consumption.

2) Steam

i) Steam is reported in terms of enthalpy. In this case, a steam table may be used to answer the question.

ii) The collected data is divided into steam generated at the plant in question, steam consumed, and steam received from the power plant.

iii) The data for the consumed fuel of the steam generated and recovered in the process is included in the consumed fuel of the process, and it is difficult to separate only the generated steam portion, so it was left as it is.

3) Fuel

i) The data collected included fuel consumed in the unit processes, i.e., polymerization, spinning, carbonization, and detoxification of the exhaust gas from the same processes.

ii) Fuel consumed in the air system, wastewater system, solid waste, and other environmental countermeasure equipment were also included in the data collection.

(4) Environmental impact data

i) For the environmental impact, the data provided by the responding companies should be based on the post-treatment one. However, since it is assumed that in most cases the actual load due to direct emissions and the load after treatment are mixed, if there is measurement data available, the measurement data was used as the object of the collected data.

ii) As for the environmental measurement equipment, the consumption of electricity, steam, fuel, etc. is considered as a data item to be collected, so if there is no

measured data for CO_2, SO_x, or NO_x in the atmospheric system impact data, the data was calculated from the energy and fuel consumed using background data.

iii) Data on solid waste, including product loss, was collected by dividing it into those that are effectively used, those that are self-disposed of or treated within the factory, and those that are taken outside the factory as industrial waste, with those that are effectively used within the factory not shown as environmental impact. However, items that are sold for value and ultimately put to effective use outside the factory but are not used inside the factory are considered to have an environmental impact.

iv) Principles of Collected Data

iv-i) Data were obtained as "NA" (not available) in cases where it was known that a load was present but no measured or estimated values were available or it was unknown whether a load was present or not.

iv-ii) In the case of "ND" (not detected), the data was considered as "0", i.e., when the measured results are not detected (below the detection limit) and when the annual amount is "less than 0.001 g/kg of product".

iv-iii) If there was no measured value, but it was clear that it was not theoretically assumed that there was an environmental impact of the process in question, it was left blank and treated as "0" for calculation purposes.

iv-iv) Data for CO and CO_2 were obtained as "as CO" and "as CO_2".

iv-v) Data for phosphorus and nitrogen compounds were obtained as "as phosphorus" and "as nitrogen".

iv-vi) Data for waste acid and alkali were obtained by mass after dewatering.

iv-vii) Data for sludge were obtained using dry conversion for both organic and inorganic sludge.

iv-viii) Data for the cinders were obtained including fly ashes.

iv-ix) Data for COD and BOD were obtained from measurements including those taken in from the natural world at the time of water intake.

5-3 Assumptions for processing (calculation) of collected data

In this section, assumptions for processing (calculation) of collected data are divided into seven categories: (1) scope of calculation, (2) calculation of electricity, (3) calculation of steam, (4) treatment of NA responses, (5) allocation, (6) calculation of

nitrogen and air, and (7) raw and sub-materials using substitute data and items excluded from the calculation. Then, the definition of content, principles for data collection, and principles for processing at the data aggregation stage are explained.

(1) Scope of calculation

Unit process data is collected and calculated as "Gate to Gate" and LCI data by raw material retrogression is collected and calculated as "Cradle to Gate". Therefore, transportation and packaging materials used for product shipment were excluded from the calculations. In addition, the transportation data of raw materials brought into the unit process were excluded from the calculation, except for various petroleum products supplied from petroleum refining complexes.

Regarding CF, examination of material recycling has been carried out on the end material in the factory and part of the used products, and utilization of milled fiber, etc. after regeneration treatment is expected. JCMA has collected reclamation data from the demonstration plant and organized it as LCI data to date. In this analysis, however, recycling was not taken into account in the estimation of LCI data for CF.

(2) Calculation of electricity

i) Electricity purchased from joint power generation companies based in petrochemical complexes, etc., or from companies specializing in power generation such as electricity and steam, which are separate companies, was treated in the same way as electricity received from power plants.

ii) It is difficult to obtain answers by separating the power consumed by the environmental countermeasure equipment into public power and power received from the power plant. However, since the ratio of power consumed by environmental countermeasure equipment to the total power consumed, including production processes, is not so large, all the power consumed in the data processing stage was prorated by the ratio of on-site generated and purchased (public power) power for the power consumed in the processes.

iii) The on-site generation power consumed by the unit process (or prorated from the power consumed by nitrogen and environmental countermeasure equipment) was calculated using the weighted average of power plant data collected from CF manufacturers in this analysis.

iv) The on-site generation power, which is counted when retroactively adding back to

the raw materials, was calculated using background data (weighted average data of power plants in the petrochemical industry).

(3) Calculation of steam

i) Steam consumed in the unit process was calculated using the weighted average of power plant data collected from CF manufacturers in this analysis.

ii) The steam, which is counted when retroactively adding back to the raw materials, was calculated using background data (weighted average data of power plants in the petrochemical industry).

iii) The paid-out steam delivered from the process is deductible, but the steam generated and recovered in the environmental countermeasure equipment and then delivered to the process is not deductible. Note that there is no recovered steam in the relevant system (CF unit process and environmental countermeasure equipment) covered in this analysis.

iv) However, in the retrospective calculation of raw materials, when the data used in the calculation as background data are based on the deduction of steam that has been generated and collected in the environmental countermeasures equipment, the data may remain intact because the data are within the range that the operation of the present analysis and the data processor does not extend.

(4) Handling of NA responses

When calculating the weighted average, the "NA" responses were excluded from the processed data and the weighted average was calculated with the other responses.

(5) Allocation

i) In processing environmental countermeasure equipment data as well as the unit process in question, it is necessary to allocate the energy and environmental impact to be borne by the product in question. In this analysis, the energy and environmental impact data for the relevant unit process is allocated based on the mass ratio of the target product, the co-product, and the by-products that are regularly used as raw materials.

ii) The energy and environmental impact data of the environmental countermeasure

equipment to be borne by the unit process in question was left to the methods normally used by the data disclosing company in data management when the environmental countermeasure equipment is shared with other processes in the establishment where the unit process is located (for example, in the case of a common wastewater treatment equipment) and delegated to them.

iii) The following are indicators of allocation in past LCI data surveys in chemical products. And this information was informed in advance to the companies disclosing the data prior to data collection.

iii-i) Allocation based on the ratio of the production volume (mass) of products produced at the plant that discharges treated substances to the countermeasure equipment in question.

iii-ii) Allocation by the ratio of the amount of treated substances (e.g., wastewater volume) that are outsourced to the countermeasure equipment in question.

iii-iii) Allocation from environmental countermeasure equipment is based on the loading ratio.

iii-iv) Allocation is based on the allocation coefficient in the accounting (budget).

iii-v) Allocation of road lighting is based on the area ratio.

iii-vi) All allocations are based on staffing ratios.

iv) Valuable off-grades were made subject to energy and other allocations for the process in question and treated the same as the target product.

(6) Calculation of nitrogen and air

i) All nitrogen was purchased externally. Unit data of the electricity and steam consumption for nitrogen was determined using the unit data based on the production performance of industrial gas manufacturers (background data). This data was created by Japan Plastic Waste Management Institute in cooperation with gas manufacturers, and is commonly used in the LCI data published in 1999, mainly for general-purpose synthetic resins (LCI data survey report for petrochemical products: Japan Plastic Waste Management Institute) and in the construction of LCI data for various chemical products, etc.

ii) However, since it was not possible to obtain information on the composition ratio of public power and on-site power generation in the electricity consumption of nitrogen, it was decided to prorate it by the composition ratio of public power and on-site

power generation in the electricity consumption of the CF manufacturing process calculated from the data collected in this study.

iii) Since the nitrogen used in the calculations here is nitrogen produced in petrochemical complexes, the calculations for on-site power generation and steam in nitrogen were performed using average data for power plants (electricity and steam) in the petrochemical industry. These data are maintained by Japan Petrochemical Industry Association (JPCA), and permission to use them was obtained from JPCA. This unit data for power plants, i.e., on-site power and steam, is an energy and environmental impact unit generated based on actual data collected from five petrochemical companies with ethylene centers.

iv) The PC carbonization process takes in air and uses oxygen from the air. For this reason, we decided not to calculate the electricity and vapor associated with the consumption of oxygen as an industrial gas, as is the case with nitrogen. In this case, the oxygen in the air is used and the unnecessary nitrogen is released into the atmosphere. However, this nitrogen is not treated as an atmospheric emission because it is simply returned from what was originally in the air (in the atmosphere). Note that the electricity consumed for air intake is included in the electricity consumed by the CF manufacturing process.

(7) Raw materials and sub-materials using substitute data, and items excluded from calculation

i) Materials input for the manufacture of equipment such as plants and ancillary facilities used in production were excluded from the calculation of LCI data.

ii) Input raw materials and auxiliary raw materials/materials for which substitute data were used are shown in Table 4. All PAN input raw materials were retroactively calculated as AN. Solvents among PC inputs were excluded from the retrospective calculation by applying the cutoff rule. There is no clear standard for the cutoff rule in ISO 14040 and other standards. In this survey, we decided to apply the cutoff rule to a portion of raw materials that is less than 5% of the total raw material input. This is based on the concept of the cutoff criteria in the LCA Guidelines for Greenhouse Gas Emission Reduction Effects of Geothermal Heat Pump Systems (March 2012, Ministry of the Environment): "In the product manufacturing sector, about 5% corresponding to the mass of the product is generally used".

iii) Of the raw materials (excluding packaging materials) input to PAN, PC, and CF listed in Table 4, excluding solvents input to PC, the total input after retroactive calculation (naphtha, reformate, LPG (Liquefied Petroleum Gas), NGL (Natural Gas Liquids),

natural gas, LNG (Liquefied Natural Gas), oil coke, coal, crude benzol, catalysts, industrial salt, quicklime, solvents, and sulfur) totaled 2.632 tons. Since the percentages of quicklime and solvents in this total are small (0.4% and 0.05%, respectively), the cut-off rule was applied, and no retroactive calculation was made. Note that the solvents here are not the solvents fed into PC, but the solvents required for the retroactive calculation of electrolyte. In addition, sulfur was treated as a reminder flow that does not impose environmental impact because sulfur is a byproduct of the petroleum refining process.

iv) In addition, there is a coagulant used in the coagulation bath that is not listed in Table 4 but is introduced here as an example. The coagulation bath is a liquid consisting of 67% DMAC and 33% water. The coagulant is usually used without replacing the coagulation bath liquid and replenished for losses, but the amount of coagulant replenishment is extremely small, less than 0.1%, so it was excluded from the data collection items.

v) Data on packaging materials used for product shipment were collected for future use but were excluded from the calculations because the scope of this survey is "Cradle to Gate," which is the exit point of the CF manufacturing process. However, we are presenting the unit data as a result of the survey so that users can make appropriate calculations according to their purposes when utilizing this data. Note that since paper tubes are used repeatedly and are basically used until they become useless, the amount used per unit weight of CF is practically as close to "zero" as possible.

Table 4 Input raw materials and auxiliary materials/materials using substitute data

Polymerization process	Acrylonitrile (AN)	AN
	Comonomer	Substitute AN
	Polymerization catalyst	Substitute AN
	Solvent	Substitute AN
Spinning process	PAN fiber oil (PG)	Calculated with PO and water
	Solvent	Apply cutoff rule
Carbonization process	Carbon fiber sizing agent	EP
	Electrolyte (sulfuric acid)	Substitute sulfuric acid
Product shipment	Packaging film (PE)	Excluded from calculation
	Paper tube	Excluded from calculation
	Outer packaging material (PE)	Excluded from calculation
	Outer packaging material (corrugated cardboard)	Excluded from calculation

NOTE: Packaging materials used at the time of product shipment were excluded from the

calculation.

5-4 Sources of data used

Table 5 lists the sources of the data used in this survey. Background data cannot be uniformly described in terms of data quality because the data sources differ depending on the data applied. Table 5 lists the year and the data creator (or the name of the cited reference) of the data used in this survey, including foreground data.

Among the background data, some data on AN, which is particularly important in the calculation of LCI data for PAN-based CF, were reviewed in this analysis and are described below.

The AN data is not only the main raw material of PAN, but also co-monomers, polymerization catalysts, solvents, and other highly confidential secondary raw materials used by different manufacturers are retroactively calculated with the AN data. Therefore, with the cooperation of Japan Acrylonitrile Producers Association, we obtained quantitative information on the current status of utilization of large amounts of by-product steam and applied partially revised data to the calculations.

In this analysis, data on the "unit process" of CF production and the "power plant of the plant with the unit process" were collected directly from the members of JCMA. Therefore, the unit process data and power plant data are foreground data. On the other hand, background data is used for the data up to the manufacturing process of various raw materials, mainly AN.

Table 5 Sources of data used

No	Category	Data name	Literature name	Year
1	B	Public electricity CO2	Calculated Greenhouse Gas Emission Data (Ministry of the Environment, Ministry of Economy, Trade and Industry), Electricity Survey and Statistics (Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry)	Fiscal Year 2014
2	B	Public electricity SOX, NOX	Data released by 10 general electric utilities, Electricity Survey and Statistics (Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry)	Fiscal Year 2014
3	B	Public electricity Energy	Electricity Survey Statistics (Agency for Natural Resources and Energy, Ministry of	Fiscal Year 2014

		consumption	Economy, Trade and Industry), List of standard calorific values by energy source (Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry)	Partially corrected on November 17, 2017
4	B	Petroleum products	LCI Preparation for Petroleum Products by Oil Type and Environmental Impact Assessment Report for Petroleum Products (Japan Petroleum Energy Center)	March 2000
5	B	Natural gas, coal	Survey Report on Comparison of Oil, LNG, and Coal Using LCA Methodology (Japan Petroleum Energy Center)	March 1999
6	B	Resource extraction and transportation	Data from reports No. 4 and No. 5 in this table are used.	-
7	B	On-site power generation, steam (Cogeneration)	LCI Data Survey Report for Petrochemical Products (Japan Plastic Waste Management Institute)	July 1999
8	B	AN	Acrylonitrile Inventory Analysis Report (Japan Acrylonitrile Producers Association) Electricity was recalculated on a 2014 basis, and byproduct steam evaluations were revised with November 2019 survey data.	2002 2000 results
9	B	PO	No literature: Representative values estimated by WIC at the request of the Urethane Raw Materials Industry Association with the cooperation of data from member manufacturers of the Japan Petrochemical Industry Association (not disclosed). However, electricity was recalculated on a 2014 basis.	2003 2000 results
10	B	PG	Calculated with PO and water due to lack of PG data. However, electricity was recalculated on a 2014 basis.	-
11	B	EP	Survey Report on the Construction of Inventory Data for Composite Materials (The Society of Japan Aerospace Companies). However, electric power was recalculated on a 2014 basis.	July 1999
12	B	Sulfuric Acid	No literature: Calculated based on data provided by the Sulfurous Acid Association of Japan (not disclosed). However, electricity	2001

			data was recalculated on a 2014 basis.	
13	B	Nitrogen gas	No literature: Representative values prepared by Japan Plastic Waste Management Institute in cooperation with the Japan Petrochemical Industry Association (not disclosed). However, electricity was recalculated on a 2014 basis.	1999
14	F	On-site power generation, steam	On-site electricity and steam used in the unit process calculations were averages calculated from data collected from members of JCMA (actual data from companies that disclosed data).	Based on actual production in 2017
15	F	PAN、PC、CF	Data prepared this time based on performance data provided by three JCMA member companies (reported in this report).	Based on actual production in 2017

Note 1: "B" in "Category" is background data and "F" is foreground data.

Note 2: AN (acrylonitrile), PO (propylene oxide), PG (propylene glycol), EP (epoxy)

Note 3: PAN (polyacrylonitrile), PC (precursor), CF (PAN-based CF)

Note 4: Energy consumption and environmental impact associated with the consumption of electricity are calculated according to No. 1 to No. 6, and are calculated as the combined amount of primary and secondary energy. Steam and fuel are calculated in the same way.

5-5 Inventory data submitted

Two types of data were estimated: unit process data and cumulative data traced back to natural resources. However, in the interest of confidentiality for the companies in the CF industry, we decided to release the cumulative data. The following is a report on the contents of the registration. The subsystem information to be registered is shown in Table 6.

Table 6 Subsystem Information

Subsystem information	Data ID	
	Classification code, Product name	2262 Carbon fiber manufacturer (in Japanese industrial classification)
	Classification code, Product name	256919 Other carbon and graphite products (selected from JLCA registration codes)
	Subsystem name	Manufacture of PAN-based carbon fibers (all processes: cradle to gate)

	Specification	High-strength CFs with tensile modulus of 230 to 250 GPa, filament counts of 12K (800 tex) to 24K (1600 tex)
	Subsystem Classification	Production
	Unit quantity	1kg
	Weight	1kg
	Allocation method	Allocation by weight ratio
	Special remarks	The CF manufacturing process consists of three major steps: polymerization of raw materials (PAN manufacturing), spinning (precursor manufacturing), and carbonization (CF manufacturing). Energy consumption and environmental impact in this data represent the total energy consumption and environmental impact of all processes (from resource mining and extraction to CF production) related to the production of 1 kg of CF (higher heating value was used to convert each energy into heat). Only the replenishment of raw materials recycled in the unit process was accounted for in each process. By-products of the unit process that are sold as valuable raw materials were treated as if they were the target products of the process, and the energy consumption and environmental impact of the process were allocated to them. The allocation was done on a weight ratio basis. The total primary energy consumption of all raw materials and fuels (electricity, steam, and directly consumed fuels) input for the production of 1 kg of CF, calculated back to the mining and extraction of resources, is **318.2 MJ**. In addition, there is **32.1 MJ** of feedstock energy, which together makes a total of **350.2 MJ**. This data was compiled by the committee of JCMA (The Japan Carbon Fiber Manufacturers Association) in JCFA (Japan Chemical Fibers Association) under contract to WIC (Industry Information Collaboration Research Center). The calculated data were subjected to critical review by three academic experts, and the final data were revised as necessary based on the review results.
Data creator	Creation date	September 6, 2022
	Name	
	Affiliation	Committee of JCMA (The Japan Carbon Fiber Manufacturers Association) in JCFA (Japan Chemical Fibers Association)

		Commissioned by WIC (Industry Information Collaboration Research Center)
	Address	7th Fl., Sen-i Kaikan, 3-1-11, Nihombashi-Honcho, Chuo-ku, Tokyo 103-0023, Japan
	E-mail address	https://www8.webcas.net/form/pub/jcma/jcmacontact-en
	Phone number	81-3-3241-2311
	FAX number	81-3-3246-0823
Data quality information	Time-related coverage	Fiscal year 2017 Results (April 1, 2017 - March 31, 2018)
	Geographical coverage	Japan
	Technology coverage	World
	Quality information	This column is to be entered by the database operator.
	Special remarks	Data collected in the unit process are based on production performance. All background data used for calculations in the cumulative data to be released to the public, with the exception of solvents, quicklime, recovered sulfur, and solid waste processing, were based on actual production data.
	References	Data prepared by Japan Petrochemical Industry Association, Japan Acrylonitrile Producers Association, and Japan Petroleum Energy Center were used for retroactive calculations of main raw materials and fuels. Electricity is from Electricity Survey Statistics FY2014 (Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry), Standard Calorific Value List by Energy Source Revised in 2017 (Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry); CO2 from electricity is from Greenhouse Gas Calculated Emissions Tabulation Results FY2014 (Ministry of the Environment and Ministry of Economy, Trade and Industry), Electricity Survey Statistics (Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry); and For SO_x and NO_x, a weighted average value based on the amount of electricity generated was calculated from values published by general transmission and distribution companies (10 electric power companies in Japan) and other sources.

As a supplement to the classification codes in the subsystem information (Table 6), CF

belongs to the ceramic industry in the national industrial classification and is classified as classification code 2262 "Carbon fiber manufacturers". Since this classification does not exist in the database of Japan Environmental Management Association for Industry, it was registered as 256919 "Other carbon and graphite products manufacturing industry" in the ceramic industry. This is annexed in Table 6.

Next, Table 7 shows the subsystem input information as cumulative inventory data (Gate to Gate) for the production of 1 kg of PAN-based CF, and Table 8 shows the output information.

Table 7 Subsystem Input Data

Category	Code	Item	Mean value	Special remarks
Energy	07	Crude oil	0.546 ℓ	The resources required to obtain fuels (specifically, consumed fuels such as naphtha, heavy oil, light oil, liquefied petroleum gas, by-product fuel oil and gas, LNG, etc.) consumed in all processes from mining of natural resources to CF production, which are derived from crude oil, are shown in terms of crude oil. All energy consumption, CO2 emissions, etc. to obtain these fuels are retroactively calculated.
	07	Natural gas	2.463 m^3	The resources required to obtain the fuels consumed in all processes from mining of natural resources to CF production, which are derived from natural gas, are shown in terms of natural gas. All energy consumption, CO2 emissions, etc. to obtain these fuels are retroactively calculated.
	06	Coal	6.354 kg	Coal consumed in all processes from mining of natural resources to CF production is shown as it is. Energy consumption, CO2 emissions, etc. to obtain coal are all retroactively calculated.
	0721	LNG (Liquefied Natural Gas)	0.260 kg	LNG consumed in all processes from mining of natural resources to CF production is shown as it is. Energy consumption, CO2 emissions, etc. to obtain LNG are all retroactively calculated.
	0721	NGL (Natural Gas Liquids)	4.393 μg	NGL consumed in all processes from mining of natural resources to CF production is shown as it is. Energy consumption, CO2 emissions, etc. to obtain NLG are all retroactively calculated.
Raw materials	07	Crude oil	3.128 ℓ	The resources necessary to obtain raw materials input for the production of CF, which are derived

				from crude oil, are shown in terms of crude oil. The energy consumed and CO2, SOx, and NOx emitted to obtain these resources are all retroactively calculated. The amount of crude oil required to calculate by-product sulfur for CF production is also added.
	07	Natural gas	0.156 m^3	The resources required to obtain the raw materials input for the production of CF, which are derived from natural gas, are shown in terms of natural gas. The energy consumed and CO2, SOx, and NOx emitted to obtain these resources are all retroactively calculated.
	06	Coal	0.015 kg	The amount of coal derived from the resources required to obtain the raw materials input for the production of CF is shown as it is. The energy consumption and emissions of CO2, SOx, and NOx to obtain these resources are all retroactively calculated.
	-	Seawater	0.161 kg	The amount of seawater required to obtain industrial salt (imported) input for the production of CF is shown. Energy consumption and emissions of CO2, SOx, and NOx to obtain industrial salt are all calculated retroactively, including the import process.
	-	Quicklime	0.009 kg	The amount of quicklime input for the production of CF is shown. Energy consumed and CO2, SOx, and NOx emitted in the process from limestone to quicklime are not retroactively calculated.
	-	Steam	0.011 kg	The amount of steam input for the production of CF is shown. Energy consumed and CO2, SOx, and NOx emitted in obtaining steam are all calculated retroactively.
	-	Air	13.905 kg	The amount of air required to obtain the oxygen input for the production of CF is shown. The energy consumed and CO2, SOx, and NOx emitted in obtaining oxygen are all calculated retroactively.
	-	Solvents	0.093 kg	The amount of solvent input for the production of CF is shown. Energy consumed and CO2, SOx, and NOx emitted in obtaining solvents are not retroactively calculated.
	-	Process water	2.712 kg	The amount of process water input for the production of CF is shown. Energy consumed and CO2, SOx, and NOx emitted in obtaining process

				water are all calculated retroactively.
	-	Recovered sulfur	0.052 kg	The amount of sulfur input for the production of CF is shown. Sulfur is recovered sulfur, a byproduct of the petroleum refining process, and no retroactive calculations have been made.

Note: The data acquisition method is a combination of actual measurement and calculation.

Table 8 Subsystem Output Data

Category	Item	Mean value	Special remarks
Environmental impact substances (Atmosphere)	**CO_2**	**19.849 kg**	The total value of the entire life cycle (from resource mining to CF production) for the production of 1 kg of CF.
	NO_x	**0.0353 kg**	
	SO_x	**0.0161 kg**	
Outsourced Waste	Solid waste	0.157 kg	Solid waste discharged in the production of CF is shown as a cumulative value from the starting material. Energy consumption, CO_2, SO_x, and NO_x emitted from the treatment of solid waste are not retroactively calculated.

Note: The data acquisition method is a combination of actual measurement and calculation.