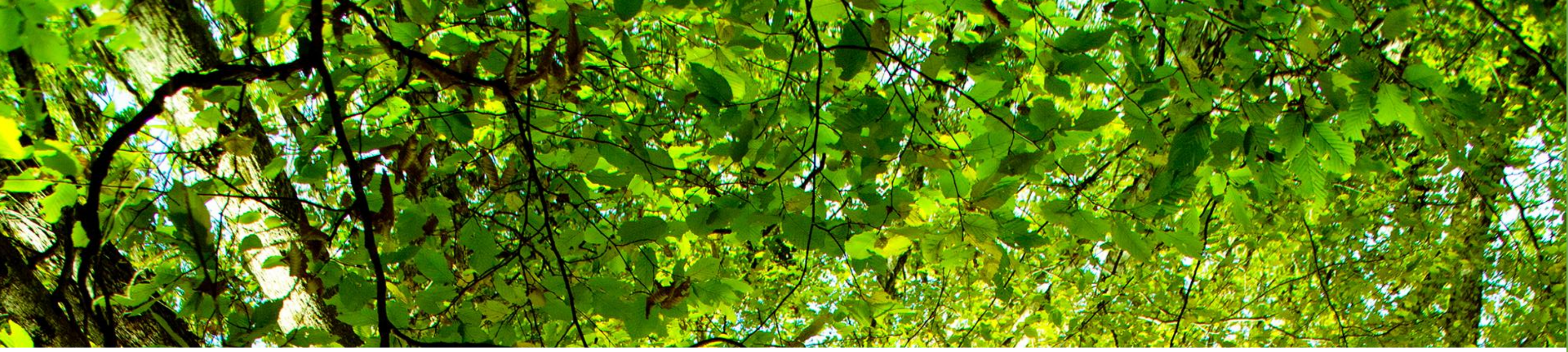
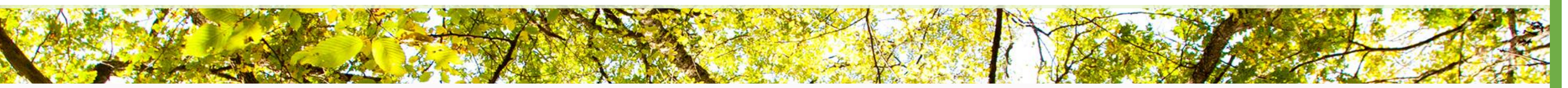


Guidelines for the Utilization and Application of Cellulose Nanofiber Towards the Decarbonization and Achievement of a Circular Economy

Summary Ver. 1.0 March, 2021



Since FY 2015, the Ministry of the Environment has been dealing with various challenges concerning "cellulose nanofiber" (CNF), which can be expected to make a huge contribution towards the decarbonization and achievement of a circular economy, with universities, manufacturers and local governments for the purpose of facilitating its practical use in society. Based on the achievements of relevant efforts, the Guidelines containing comprehensive as well as practical information have now been compiled so that users can select a suitable type of CNF for an intended purpose in an appropriate manner and can efficiently develop and manufacture products using CNF.

環境省
Ministry of the Environment

5. Introduction of Committee Members Cooperated with the Preparation of the Guidelines

A planning committee was established to prepare the Guidelines and its members debated for a period of one year. Here, the committee members cooperated with the preparation of the Guidelines are introduced.

■Planning Committee Chairperson
NISHINO, Takashi (Professor, Applied Chemistry Course, Graduate School of Engineering, Kobe University)

I have been researching cellulose from the viewpoint of chemistry at my Graduate School of Engineering. Humans have liberally used natural macromolecular celluloses in the form of cotton/hemp, wood and paper. When these celluloses are loosened, their diameter eventually reaches the nano level, attracting much attention as ecological nanofibers. Although these nanofibers are somewhat mischievous, they can offer an amazing performance once suitable roles are assigned to them. I have now compiled the Guidelines for the utilization and application of CNF together with my colleagues. I hope that you find exciting roles for CNF.

■Committee Members

Name (Affiliation; Position)	Self-Introduction
ISOGAI, Akira (Special Research Professor, Tokyo University)	CNF manufactured from recyclable plant cellulose fiber is a new bio nanomaterial which can partially replace fossil resources. The utilization of the CNF's advantages and functions for various general purpose applications and advanced materials can be expected to lead to the creation of sustainable social foundations and the prevention of global warming.
ENDO, Takashi (Leader, Cellulose Materials Group, Research Institute for Sustainable Chemistry, National Institute of Advanced Industrial Science and Technology (AIST) Chugoku Center)	At present, our ongoing CNF-related R&D activities feature such themes as manufacturing technology, characteristics evaluation technology, resin and rubber composite development technology and functionalization and food application technology. Any effort to develop materials exploiting CNF's unique characteristics must be refined from various aspects. I hope you become involved in R&D of CNF to come up with new ideas.
HATTORI, Nobuaki (Professor Emeritus, Tokyo University of Agriculture and Technology)	My specialist field is the machining of wood. I have been engaged in research on the application of lasers to wood processing, in-sizing and noise reduction of woodworking machinery among others. Recent research focuses on the development of fire-resistant laminated wood and life-cycle assessment (LCA) of wood products. I have cooperated with the work to prepare the Guidelines from the viewpoint of LCA, hoping for the wide use of truly environment-friendly CNF products.
NOGI, Masaya (Professor, Department of Functionalized Natural Materials, Institute of Scientific and Industrial Research, Osaka University)	From the earlier target of achieving a "low" carbon society, the achievement of a "decarbonized society" has now become a pressing task in recent years. I hope that the new Guidelines will become a valuable source of information to challenge this important but difficult task so that the practical utilization of CNF and a decarbonized society can be achieved as soon as possible.
YANO, Hiroyuki (Professor, Laboratory of Active Bio-Based Materials, Research Institute for Sustainable Humanosphere, Kyoto University)	CNF as a carbon-neutral high performance nanofiber with many hidden possibilities is a gift from the world of plants. By making the best use of the million years of plant history of our Earth, I hope to move together with you all to materialize the practical use of CNF materials in society with an open-innovation approach with a view to achieving zero GHG emission.
TAKIUE, Kotaro (Head, Department of Material Technology Planning, Material Technology Headquarters, Teijin Limited)	CNF is expected to transform itself to high performance composite materials and merchandise contributing to a sustainable society when combined with various materials. Using the Guidelines, I am determined to press ahead to materialize various practical applications in society with a view to achieving the first environment-friendly society in the world.
NAIKI, Masahiro (Head, Engineering Plastics R&D Department, Ube Industries, Ltd.)	Ube Industries, Ltd. is advancing the development of new composite materials using nylon and CNF. Along with contributions to a recycling society through the utilization of CNF as a natural material, we consider such development to be a new business opportunity, aiming at establishing a de facto standard in the resin field using CNF.
YAMAOKA, Hiroyasu (Senior Staff, Corporate Planning Division, Mitsui Chemicals, Inc.)	We are hoping that functions which are acquired through the use of CNF as an additive to various resins, etc. will provide solutions for our clients and also lead to the achievement of a sustainable society. It will be my pleasure if the Guidelines increase your interest in CNF and help you to move forward to the practical application of CNF.

Affiliation and Position as of March 2021

6. Places to Obtain the Guidelines (Main Version)

Please refer to the following website for details of "the Guidelines for the Utilization and Application of Cellulose Nanofiber (Main Version)".

http://www.env.go.jp/earth/ondanka/cnf.html

環境省　CNF　ガイドライン

Guidelines for the Utilization and Application of Cellulose Nanofiber (Abridged Version) (published in March, 2021)

■Publisher:
Ministry of the Environment Government of Japan
Godochosha No. 5, Kasumigaseki 1-2-2, Chiyoda-ku, Tokyo 100-8975, Japan
Tel: +81-(0)3-3581-3351　https://www.env.go.jp/

■Production:
EX Research Institute Ltd.
Sustainability Design Division TEL +81-3-5956-7504
Deloitte Tohmatsu Consulting LLC
Public Sector TEL +81-3-6867-8916
Sustainable Management Promotion Organization
LCA Center TEL +81-3-5209-7708

1. Outline of Cellulose Nanofiber (CNF)

■Characteristics of CNF

→Refer to "Introduction 1: Characteristics of CNF"

Cellulose nanofiber (hereinafter referred to as "CNF") is a plant-derived next generation material. It is nano-sized fiber produced through chemical and mechanical processes from wood, etc. It has a high specific surface area and has such characteristics as high strength as well as modulus of elasticity despite its light weight. Using these characteristics, many positive environmental effects can be expected by developing and using merchandises utilizing CNF.

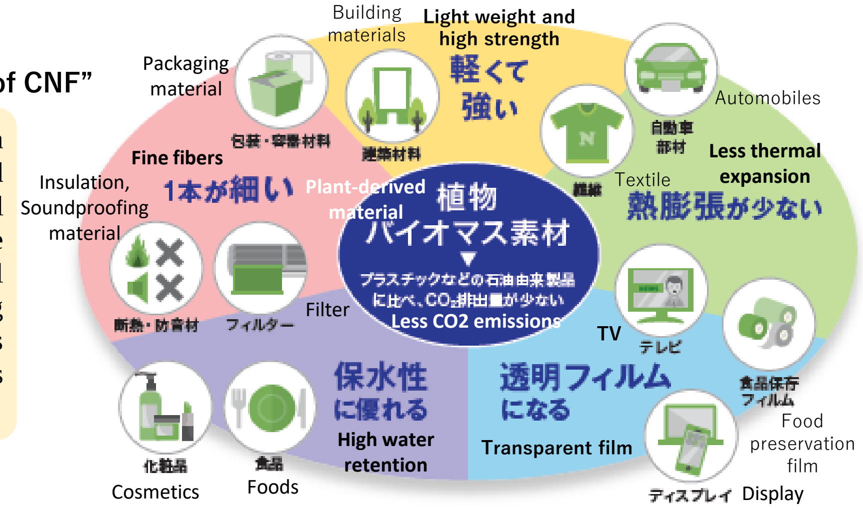


Table1. Characteristics of CNF

Characteristics of CNF	Expected Environmental and Other Effects
Light weight and high strength material	Reduction of energy consumption and CO_2 emission through its application to structural materials
Plant-derived material	Reduction of CO_2 emission as an alternative to conventional materials (plastic, etc.)
Highly recyclable material	Contribution to the achievement of a circular economy due to an improved level of recyclability
Procurement material from domestic forest resources	Contribution to forest conservation and measures designed to improve CO_2 absorption sources in Japan
New material	Possible creation of local industries which utilize equipment, human resources, technologies, etc. associated with CNF

■Types of CNF

→Refer to "Introduction 4: Scope of Application" and "Chapter1-1.1: What is CNF?"

CNF is a type of nanocellulose. Depending on the width and length of the fiber and original raw material, nanocellulose can be classified into different types (such as cellulose nanofiber, cellulose nanocrystal and bacteria nanofiber). Because there is no unified definition for CNF, it can be referred to as microfibrillated cellulose or cellulose nanofibrils.
In the Guidelines, CNF is defined as nanocellulose which has a width of 3 – 100 nm, length of 5 µm or more and a high aspect ratio and which is produced through a mechanical defibrating process.

Table2. Classification of Nanocellulose

Type	Nanocellulose: Cellulose Nanofiber (CNF)	Cellulose Nanocrystal (CNC)	Bacteria Nanocellulose
Width	3 – 100 nm	100 – 50 nm	20 – 100 nm
Length	< 100 µm	100 – 500 µm	1.5 – 5.0 µm
Non-crystalline	Yes	No	Yes

Source: Partially added to the table from the "Report for the Feasibility Study on the Creation of Cellulose Nanofiber-Related Industries in the Chugoku Region" By the Chugoku Industrial Innovation Center (March, 2016).

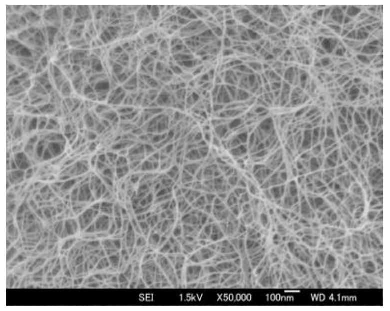


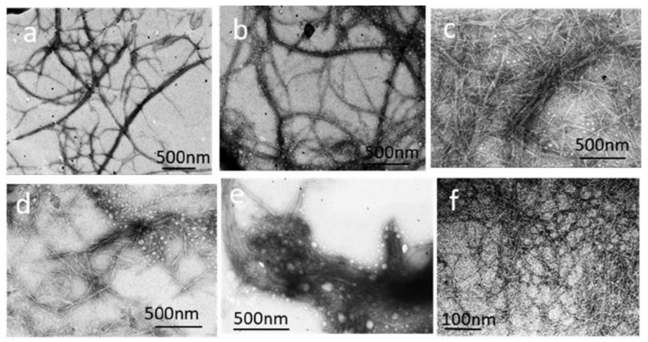
Fig1. CNF in wood cell wall

Source: Research Institute for Sustainable Humanosphere, Kyoto University

■Manufacturing Methods of CNF and Their Characteristics

→Refer to "Chapter 1-1.1: What is CNF?"

For the production of CNF, it is necessary for raw materials to undergo a refining process followed by a defibrating process using a mechanical device, etc. While CNF has multiple characteristics, the emerging characteristics differ depending on the specific raw material, pulping method and processing method. For this reason, it is important to know the type of raw material used, the processing method used for manufacture and the relationship between the functions and intended purpose of use.



Water jet method (diagonal collision method) (a: derived from Kraft cooking; b: derived from soda AQ cooking)
Enzymatic hydrolysis method (c: derived from Kraft cooking; d: derived from soda AQ cooking)
e: wood powder grinder processing method
f: TEMPO processing method (derived from Kraft cooking)

Fig2. Transmission electron microscope photograph of CNF by manufacturing method

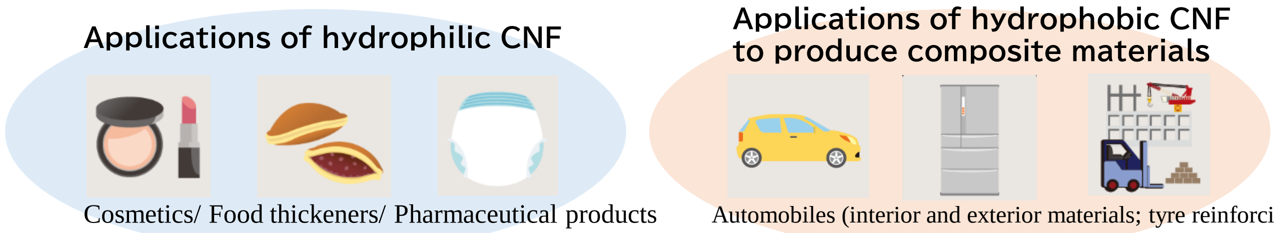
Source: "Raw Materials Evaluation Report for Promotion of the Use of Cellulose Nanofiber" (Abridged Version), March, 2020 by the New Energy and Industrial Technology Development Organization (NEDO).

2. Trends of CNF-Related Technological Development, Production and Commercialization in Japan

■State of Dissemination of CNF

→Refer to "Chapter 1-1.3: Purposes of Use of CNF" and "Chapter 2 -2.1: State of Dissemination of CNF and Future Marketing Prospects"

As of 2020, several hydrophilic products using CNF have been developed and marketed. Meanwhile, many potential composite applications of CNF, such as an additive to plastics, etc., where it can offer a high level of CO2 reduction effect (automobiles, household electrical appliances, house construction materials, etc.) have reached the demonstration stage for commercial development.



Cosmetics/ Food thickeners/ Pharmaceutical products

Automobiles (interior and exterior materials; tyre reinforcing materials)/ Household electrical appliances/ House construction materials)

Fig3. Examples of commodities already marketed or at the R & D stage

■State of Production of Raw Materials of CNF

→Refer to "Chapter 2-2.3: State of Production and Production System of Raw Materials of CNF"

As of April, 2020, there is a total of 25 CNF manufacturing plants in operation and one new plant is expected to start operation in 2021.
By manufacturing method, mechanical methods are most frequently used. There are three plants each for the TEMPO-oxidation method and modified pulp direct kneading process (so-called "Kyoto process"). Please refer to the Full Version for details.

＊ Plant data (plant name, production capacity and manufacturing method) corresponding to the number in the map is listed on Page 51 of the Full Version.

Fig4. Panoramic view of Daio Paper Corporation's Mishima Mill where a CNF plant is located (No. 9 on the map on Fig5)

Source: Courtesy of Daio Paper Corporation

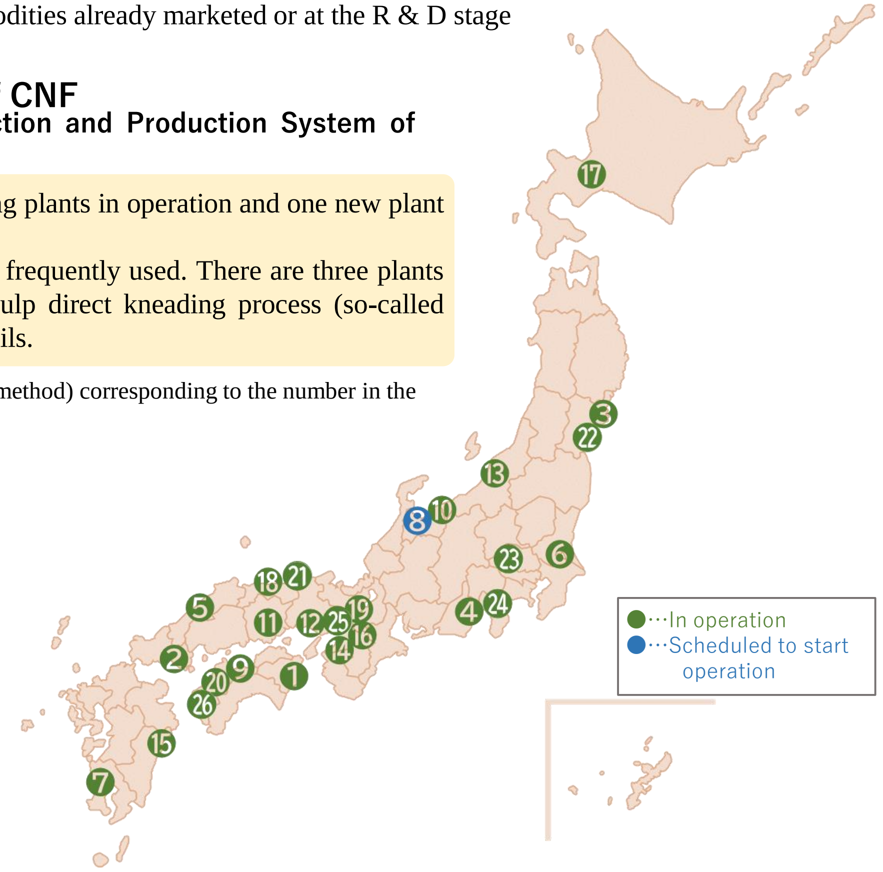


Fig5. Map of CNF Manufacturing Plants (as of April, 2020)

Sources: Kansai Bureau of Economy, Trade and Industry and Kyoto Municipal Institute of Industrial Technology and Culture: "List of Companies Providing Cellulose Nanofiber-Related Samples (9th Edition)" (Feb. 27, 2020) and various public information sources

■Future Marketing Prospects of CNF

→Refer to "Chapter 2-2.1: State of Dissemination of CNF and Future Marketing Prospects"

The global market size for fiber reinforced composite materials for was estimated to be 8.6 trillion JPY in FY 2016. The assumed application fields include transportation (automobiles), construction, electrics/ electronics, pipes/tanks, consumer goods, etc. Assuming that CNF composite resins are introduced to account for a sizable proportion, the market size for CNF composite resins can be expected to amount to several trillion JPY.

＊1 JPY= 0.00930 USD（March 1st, 2021)

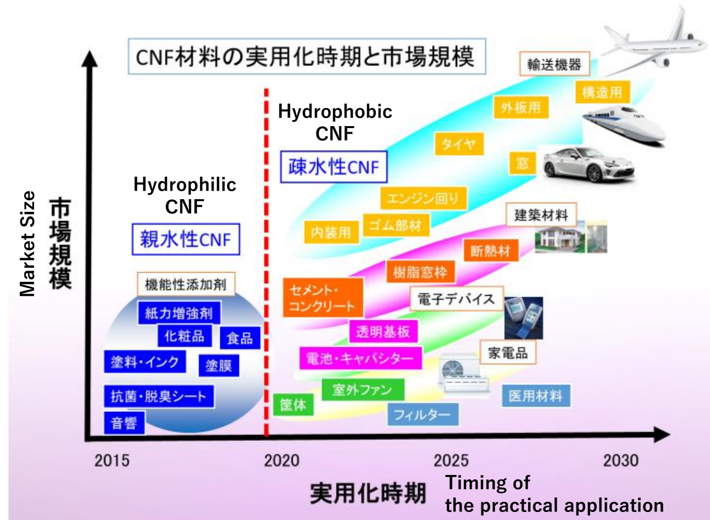


Fig6. Timing of the practical application of CNF materials and market size

Source: Professor Yano, Kyoto University

■Division of Work Relating to CNF among Relevant Ministries

→Refer to “Chapter 3-3.1: Entire Image of MOEJ’s Efforts to Achieve the Practical Use of CNF in Society”

Various ministries in Japan are playing their part in the utilization and application of CNF. The Ministry of the Environment, Government of Japan (MOEJ) has been conducting the evaluation and demonstration of the CO2 reduction effects of CNF and other next generation materials contributing to the medium to long-term reduction of energy use-derived CO2 emission and also control technologies to solve problems associated with CNF recycling.

Introduction of Main MOEJ Projects Relating to CNF

Project for the Planning of Low Carbonization Measures in the Manufacturing Process of CNF Products (FY 2015 – FY 2017)

Using the backcasting method starting from end products, various evaluation and verification exercises were conducted to identify problems at the time of manufacturing and practical use in society and prepare measures to deal with them. These exercises aimed at realizing the early practical use of CNF in society by solving possible problems in advance.

Project for Modelling of Performance Evaluation of Cellulose Nanofibers (FY 2017 – FY 2019)

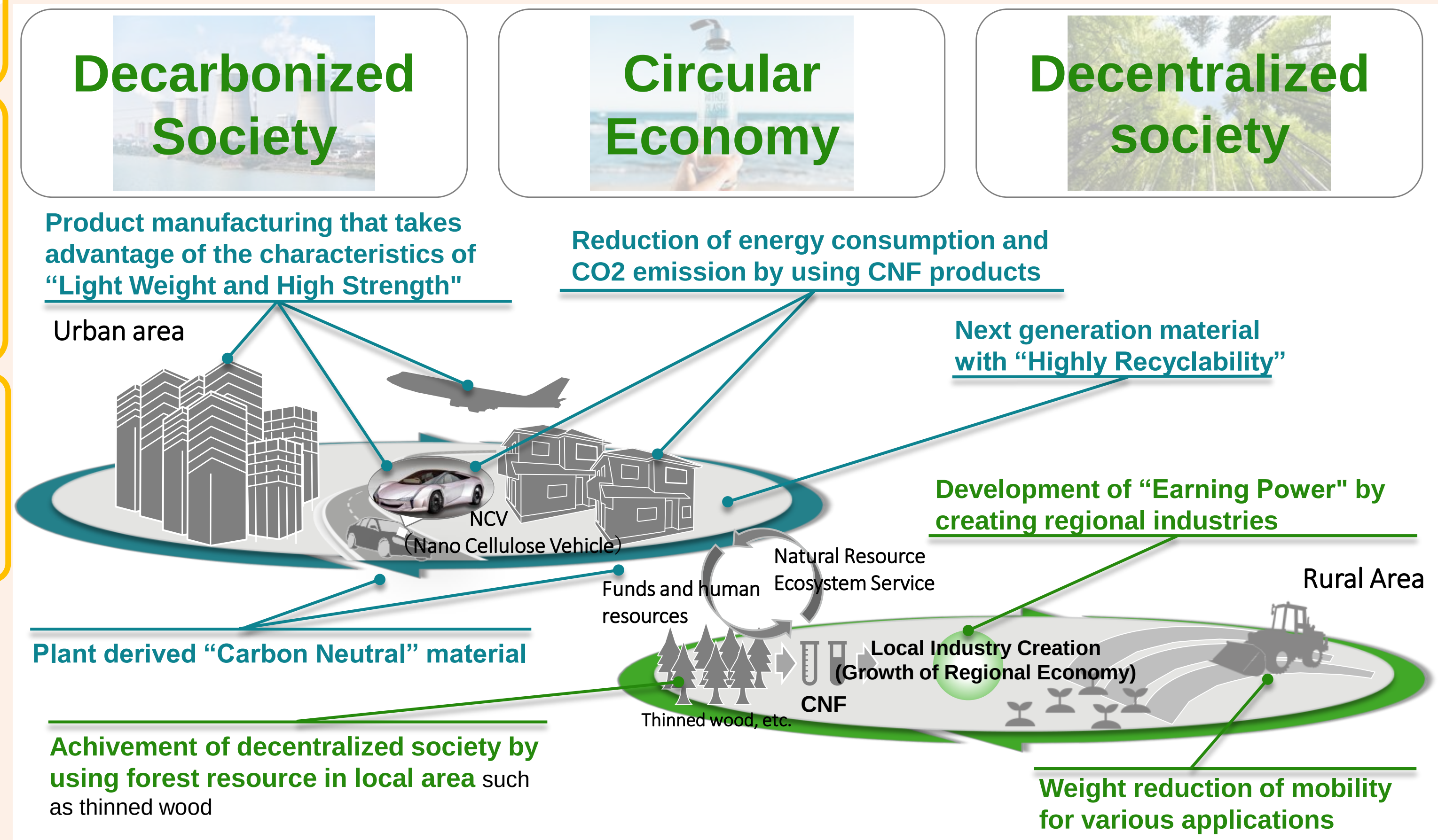
In collaboration with relevant material manufacturers and product makers, possible applications for lightweight CNF materials were developed and the performance of these materials was evaluated in such fields as automobiles, household electrical appliances, housing/construction materials, etc. where there is a large potential for CO2 reduction because of the large domestic market.

Project for Demonstration of Potential Measures to Solve Problems Arising from CNF Recycling (FY 2017 – FY 2019)

The easy recyclability at the manufacturing stage of composite CNF resins (materials) and performance of recycling materials were evaluated and solutions to perceived problems were demonstrated.

Future Image of a “Decarbonized Society, Circular Economy and Decentralized Society” Utilizing CNF as Aimed at by the MOEJ

→ Refer to “Introduction 2: Image of a Decarbonized Society Utilizing CNF as Drawn by the MOEJ”



The MOEJ has clearly put forward a future image of “a decarbonized society, circular economy and decentralized society” utilizing CNF, indicating the direction for policies and measures designed to achieve these targets so that these policies, etc. will form the foundations for efforts to use CNF and to increase investment in CNF-related businesses.

In 2016, the NCV (Nano Cellulose Vehicle Project) started as an entrusted project of the MOEJ. Kyoto University acted as the leader of the project in a consortium made up of a total of 22 universities, research institutes, private enterprises, etc. As a positive achievement of this project, a concept car manufactured with composite CNF materials was introduced at the 2019 Tokyo Motor Show for the first time.

→Refer to “Column (Page 58 ~) in Chapter 3-3.1: Entire Image of the MOEJ’s Efforts to Achieve the Practical Use of CNF in Society”

Fig7. NCV introduced for the first time in 2019

Table3. Technological Potential for NCV (Petrol-Powered) in 2020

Contents	Technological Potential
Vehicle weight reduction (including secondary weight reduction)	16%
Fuel efficiency improvement effect (including engine downsizing)	11%
Lifecycle CO_2 emission reduction effect (efficient mass production scenario for CNF)	2t-CO_2e/vehicle

NCV Nano Cellulose Vehicle Project

■Current Selling Prices of CNF

→Refer to “Chapter 3-3.2: Outline of CNF-Related Projects”

Based on data provided by the entrustee for the Project for Modelling of Performance Evaluation of Cellulose Nanofibers of the MOEJ and other information, the current selling prices of CNF by manufacturing method are sorted. The cheapest price found (500 JPY – several tens of thousands JPY /kg) is for CNF produced by the mechanical processing method. In contrast, the price based on such chemical treatment processes as the TEMPO processing and modified pulp direct kneading methods ranges from 3,000 JPY to several tens of thousands JPY /kg (10 – 30% CNF equivalent). Such a price difference is assumed to reflect the level of defibration of CNF and number of treatment processes involved in manufacturing.

The market price of CNF is determined by the type of its application and quality of corresponding product. In highly value-added fields (pharmaceutical products, etc.), business transaction is feasible even if the selling price is high. For structural applications (automobiles, household electrical appliances, construction materials, etc.), a high market price cannot be expected despite a large market size, making it necessary to lower the current selling price to expand the use of CNF.

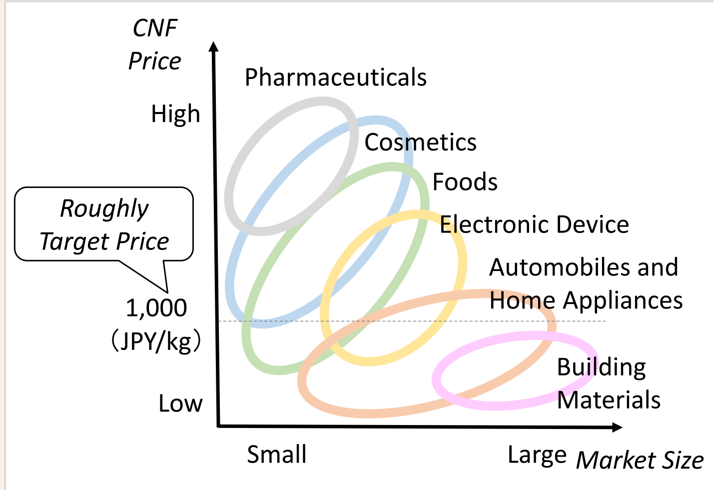


Fig8. Conceptual diagram of market size and price by type of CNF application

Example of Region-Based Efforts

■Fuji City, Shizuoka Prefecture

In Shizuoka Prefecture and Fuji City where the paper industry is long established as a major local industry due to forests, a regional consortium has been formed under administrative leadership to provide vital information and to assist cooperation between enterprises with a view to creating new industries using CNF.

→ Refer to “Chapter 3-3.3: Creation of Local Industries Using CNF”

Fig.9 Examples of merchandise developed by platform members for practical use

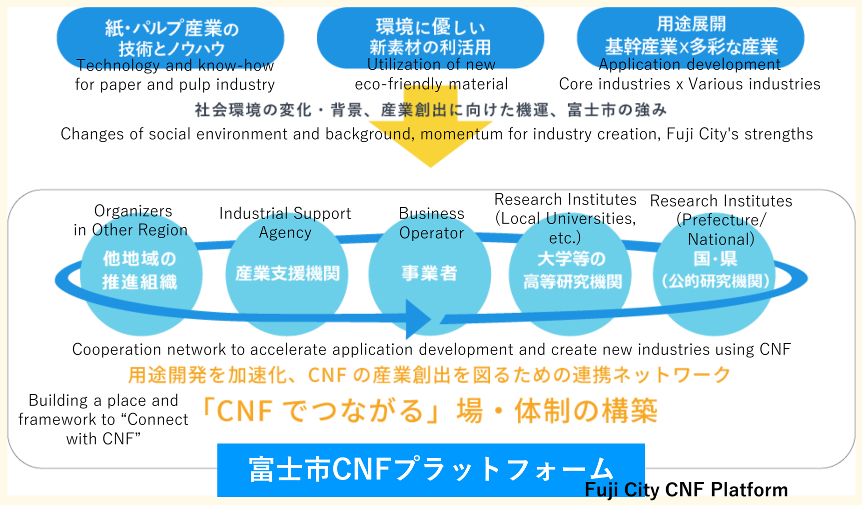


Fig10. Fuji City CNF Platform

Sources: Fuji City platform website

Question 1: Who are the targets of the Guidelines? What is the scope of the contents of the Guidelines?

The assumed readers of the Guidelines are all stakeholders involved in the manufacture of CNF, R&D of products using CNF and actual use of CNF.
The scope of the Guidelines covers the entire supply chain of CNF, primarily featuring the stages from manufacture to transportation and products using CNF.

→Refer to "Introduction 3: Target Readers" and "Introduction 4: Scope of Application" of the Main Version

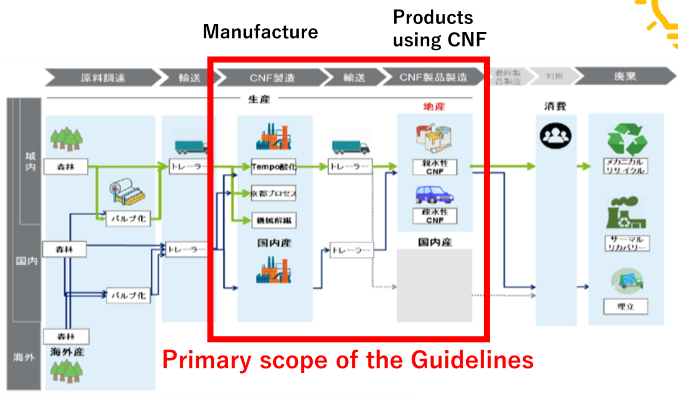


Fig.11 Entire image of the CNF supply chain

Question 2: How have MOEJ projects subsequently developed into efforts by enterprises?

Some enterprises have continued their own technological development efforts while others have already developed products or entered into joint research with other universities and/or research institutes.

←Daio Paper Corporation: Toilet wipes

Panasonic:→ Cordless vacuum cleaner

⇒Refer to "Chapter 3 : Contents of CNF social implementation efforts by the MOEJ" and Separate Volume 1 : Achievement summary of MOEJ Projects Relating to CNF" of the Main Version

Question 3: What are the local advantages of the creation of local industries using CNF? What roles are the main local players expected to play for the creation of local industries?

The expected positive effects include an increase of the local GDP, lowering of the unemployment rate and increase of the average hourly wage.
Trial calculations by the MOEJ have produced the following results (in the case where 43,000 tons of masterbatch containing 10% CNF are produced annually).

- Amount of newly created local demand: approximately 127 billion JPY
- Real GDP growth rate: approximately 4%
- Number of induced employment: approximately 2,500

Table4. Functions required of a local consortium

Necessary Human Resources		Description of Role
Organizer (Local Government, etc.)		Lead the collaboration and active participation of many stakeholders
Coordinator		Accurately guide and support the project until consensus building
Key Persons (Intellectuals, etc.)		As an expert, accurate advice for promoting initiatives (If necessary) Meeting coordinator
Implementing Entity	Business Operators	Implement projects Create new business
Implementing Entity	Forestry Association, etc.	Disclose information related to production, transportation functions and supply and demand
Administration (Central Government)		Provide information on issues such as regulations and measures that can be supported by the national government

One key point to achieve these positive effects is "to secure an enterprise(s) which locally manufactures products" in addition to the establishment of a standard supply chain. Moreover, cooperation with enterprises and knowledgeable persons inside and outside a specific locality is necessary for the creation of outlets for CNF and an increase of the demand.
Local governments are expected to play a leading role in such cooperation and their efforts together with neighboring local governments to create local industries will lead to the vitalization of the entire area.

→Refer to "Chapter 3-3.3: Creation of Local Industries Using CNF"
The section referred to above lists concrete numerical values, etc. for the economic and employment creation effects based on case studies using multiple patterns.

Question 4: Recyclability is mentioned as one characteristic of CNF. What advantages does composite CNF material have compared to other materials?

Compared to GFRP (glass fiber reinforced plastic) and CFRP (carbon fiber reinforced plastic), both of which have mechanical properties similar to those of composite CNF material, composite CNF material has such characteristics as less property deterioration after repetitive recycling due to few ruptures of the fibers during recycling. Moreover, thermal recovery is applicable to composite CNF material just like paper and plastic because of the combustibility of the plant-based raw materials for CNF.

Table5. Comparison of Recycling-Related Characteristics by Type of Material

	Material Recycling	Thermal Recovery
Composite CNF material	Highly feasible due to less property deterioration, in turn due to few ruptures of the fibers during recycling.	Feasible thermal recovery due to the combustibility of such raw materials as wood, etc.
GFRP (glass fiber reinforced plastic) CFRP (carbon fiber reinforced plastic)	Less feasible due to difficult processing, in turn caused by the high level of heat resistance and also due to lowering of the usage value as recycling shortens the fiber length.	Less feasible due to the problems of a low processing efficiency, etc., in turn caused by such properties as incombustibility, fire-resistance and/or heat resistance.

→Refer to "Chapter 4: Recycling of CNF" in the Main Version

Question 5: How much can CO2 emission be reduced by the utilization of CNF? How is such reduction calculated?

By exploiting its characteristics, CNF can be expected to respond to various social conditions concerning sustainability through business activities.
Effective ways for enterprises, etc. to market products responding to the social conditions include quantitative review of the advantages of utilizing CNF and communication with stakeholders based on the review results.
From such viewpoint, there has been increasing importance of LCA, especially establishing lifecycle CO_2 (LCCO2) from the procurement stage of raw materials to the disposal stage, and the effective use of the obtained data in addition to CO_2 data during the period of active use.
The CO_2 reduction volume can be calculated following the flow in the diagram on the right. The estimation result for petrol engine cars incorporating CNF materials shows that there is a CO_2 reduction effect to the tune of 2 tons per car compared to conventional petrol engine cars. In the Main Version, similar CO_2 estimation results are listed for other types of products.

Step 1: Calculation of the GHG emission volume of the target products, etc. for evaluation

↓

Step 2: Calculation of the GHG emission volume of comparison products

↓

Step 3: Calculation of the CO_2 reduction volume (difference between the target products and comparison products) and potential reduction volume (total CO_2 reduction volume following the popular use of CNF products)

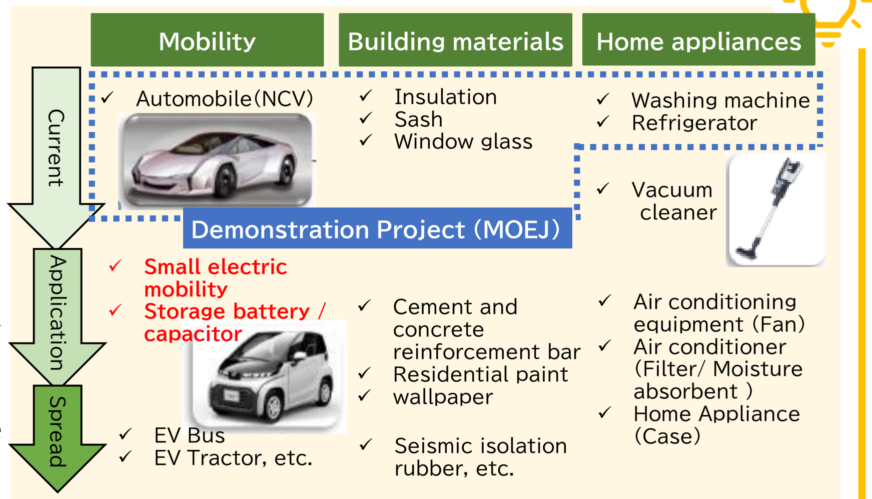
→Refer to "Chapter 5: Calculation of the CO_2 Reduction Effects of CNF" in the Main Version and "Separate Volume 3: Guidelines for Calculation of the GHG Reduction Effects of CNF"

Question 6: What are the assumed new fields for CNF application in the future and what are the presently assumed issues to be dealt with?

From the viewpoint of reducing the environmental load through global warming control measures, etc., the MOEJ will continue to promote the application of CNF, particularly focusing on the three fields of mobility, house construction materials and household electrical appliances. Particularly promising fields for development are "small electrical mobility products" and "batteries/condensors".
The principal issues assumed at present are listed below.

- Improvement of performance and guarantee of quality
- Reduction of manufacturing and transportation costs
- Establishment of recycling methods, etc.

The MOEJ is hoping that the Guidelines will provide the opportunity for the utilization and application of CNF towards the achievement of a decarbonated society and a circular economy and society.



→Refer to "Chapter 6: Towards the Future Utilization and Application of CNF"