

CNF: Transforming Next-Generation Manufacturing

Exploring Practical Implementation through
Performance, Research and LCA



Ministry of the Environment
Nano Cellulose Promotion

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Foreword

Cellulose is believed to have originated in the oceans more than one billion years ago. While the Earth itself formed approximately 4.6 billion years ago, cellulose has a history that spans an immense time scale comparable to that of our planet. Life moved onto land around 500 million years ago, and over this vast period, organisms capable of feeding on cellulose emerged. As a result, cellulose has essentially become a biodegradable material. Many technologies have already been developed to control its biodegradability, making it possible to transform cellulose into durable materials with a low environmental impact.

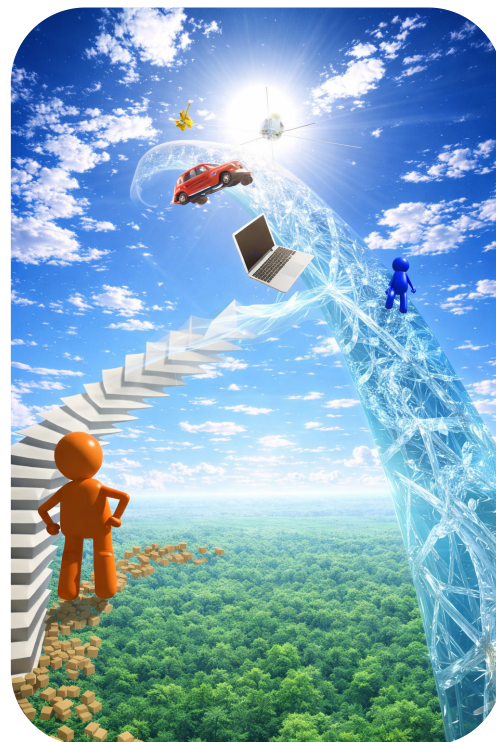
In addition, metals, plastics, and ceramics, which form the foundation of modern industry, are manufactured through processes that generally generate CO₂ emissions. In contrast, plants produce cellulose through photosynthesis by absorbing CO₂ from the atmosphere. This is one of the key characteristics that distinguishes cellulose from conventional industrial materials.

In recent years, attention has focused not only on these environmental advantages but also on the exceptional structural properties of cellulose nanofiber (CNF). Cellulose produced by plants exists in the form of crystalline nanofibers, known as fully extended-chain crystals. CNF has approximately one-fifth the density of steel while exhibiting more than five times its strength. It also maintains its strength and stiffness across an exceptionally wide temperature range, from approximately -200° C to +200° C, with very little change in performance.

Since the beginning of the 21st century, the development of materials that take advantage of these remarkable properties has accelerated rapidly around the world. In particular, lightweight, high-strength CNF is attracting attention for applications in automobiles and other mobility sectors. However, cost remains a major barrier to its widespread adoption.

Overcoming this barrier requires close collaboration between CNF manufacturers and end users. The Ministry of the Environment's "Nano Cellulose Promotion (NCP)" connects CNF manufacturers and user companies by providing free samples, customizing materials to meet specific application requirements, and evaluating their environmental performance through Life Cycle Assessment (LCA) and other approaches.

Through these activities, the project supports the practical implementation of CNF materials while helping overcome cost and performance barriers. CNF materials tailored to specific applications can be provided under a simple NDA.



Why not join us in pioneering this uncharted field and take Japanese-born sustainable materials to the world?

Next-Generation Material What is Cellulose Nanofiber (CNF)

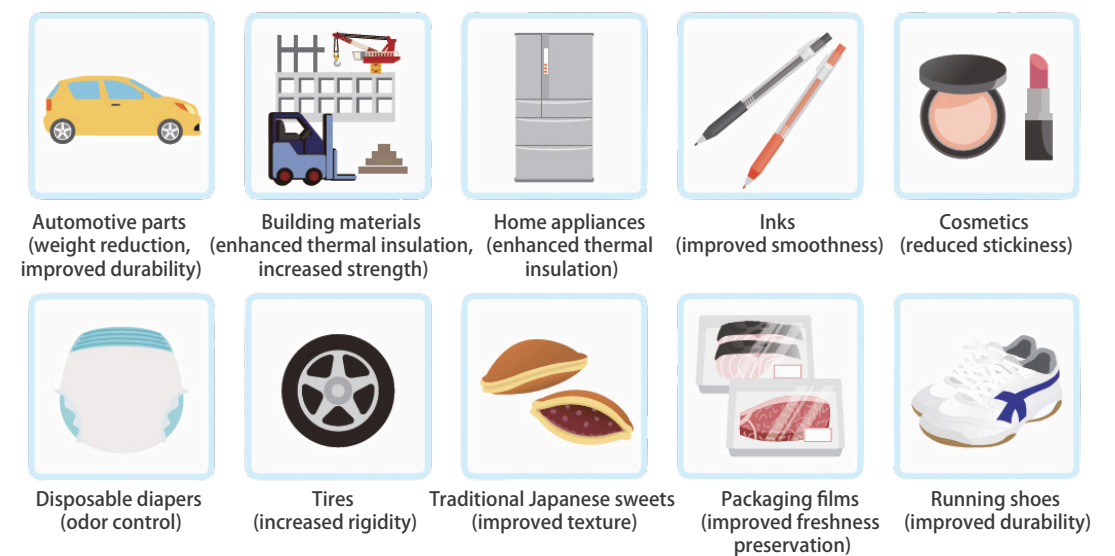
Outline

- Forests cover approximately 70% of Japan's land area, making them a valuable natural resource.
- As a resource-poor country, Japan relies heavily on imports, making greater utilization of domestic resources an important challenge.
- As a renewable material, CNF is expected to contribute to the transition toward a circular economy and is attracting growing interest for its wide range of potential applications.

What is CNF

- Cellulose nanofiber (CNF) is a nano-sized fibrous material produced from plant resources such as wood through chemical and mechanical processing.
- Lightweight, strong, biodegradable, and resistant to thermal expansion, CNF is attracting attention as a next-generation material with low environmental impact, with applications expanding in automobiles, home appliances, housing, and construction materials.
- Made from renewable and carbon-neutral resources such as forests and plant biomass, CNF also holds promise for sustainable resource use. The Ministry of the Environment supports the development and practical implementation of CNF-based products toward a circular economy.

CNF Application



CNF Production Process



CNF × Circular Economy

What is Circular Economy?

To contribute to sustainable development, the circular economy aims to move away from a “linear” economy, in which resources are used once and discarded, and instead keep products, materials, and resources in use for as long as possible.

By keeping the value of resources in circulation through repair, reuse, and recycling, the circular economy seeks to reduce waste and resource consumption, minimize environmental impacts, and help build a more sustainable society.

The Role and Importance of Forests in the Circular Economy

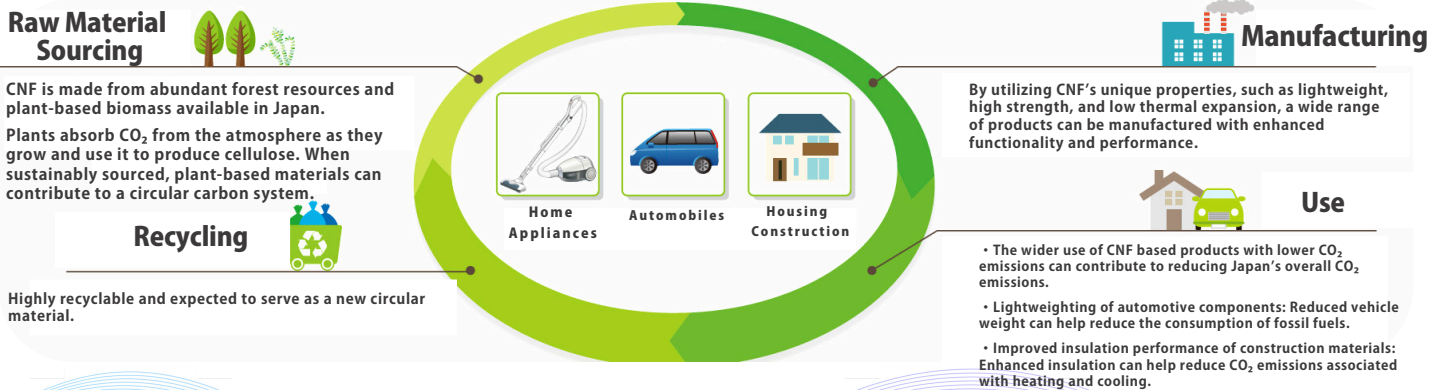
- ◆ **Environment:** Utilization as a renewable biomass resource
- ◆ **Economy:** A foundation for supporting local economies and creating new value
- ◆ **Society:** A foundation for lifestyles in harmony with nature

Achieving a Circular Economy through the Use of CNF

To achieve a circular economy, it is essential to design products with circularity in mind and to select materials that support such designs. Cellulose nanofiber (CNF) is derived from renewable, plant-based resources. By taking advantage of its properties, such as lightweight and high strength, CNF can enable products to be made lighter and more functional. This can help reduce the amount of material required and extend product lifespans, thereby contributing to reduced resource consumption and waste generation.

Furthermore, by partially replacing materials derived from fossil resources and expanding design flexibility, CNF supports the development of products that combine environmental considerations with high functionality.

By incorporating circular thinking at the material level, CNF opens up new possibilities for sustainable manufacturing.



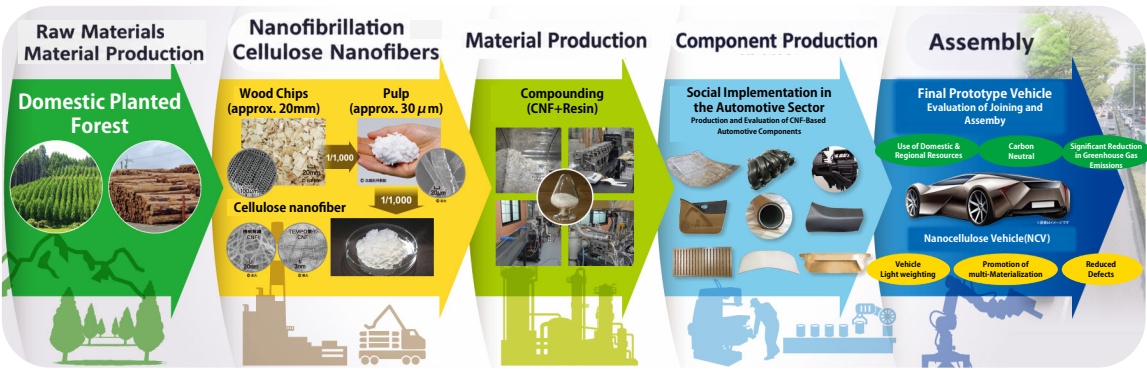
Visualizing Environmental Impacts through LCA

Life Cycle Assessment (LCA)

Life Cycle Assessment (LCA) is a method for evaluating and quantifying the environmental impacts of products and services throughout their entire life cycle, from raw material sourcing and manufacturing to use and end-of-life.

For new materials such as cellulose nanofiber (CNF), which is derived from renewable resources, LCA helps visualize the resources and energy consumed at each stage and the resulting environmental impacts. This enables the value of CNF to be communicated based on a comprehensive assessment of its environmental performance.

LCA is an important tool for rethinking how we approach the environment in manufacturing and for supporting more sustainable choices.

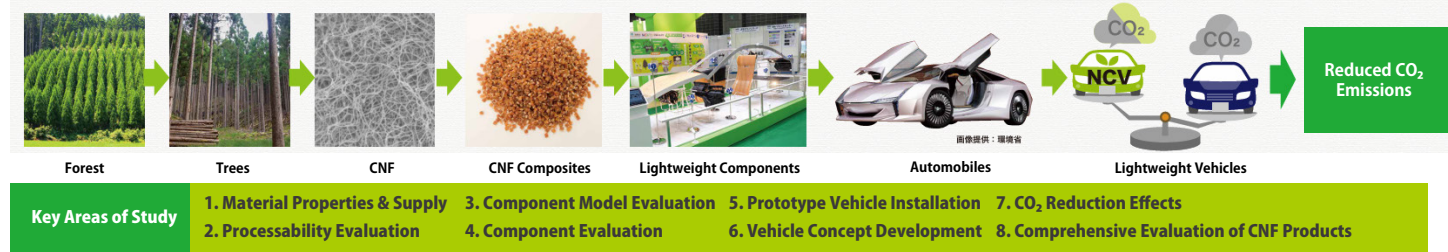


◆NCV : Nano Cellulose Vehicle Project

This project was carried out in 2020 by 22 universities, research institutions, and companies that shared the goal of developing and actually manufacturing a vehicle using CNF (cellulose nanofiber), a next-generation material, with a target of approximately 10% weight reduction.

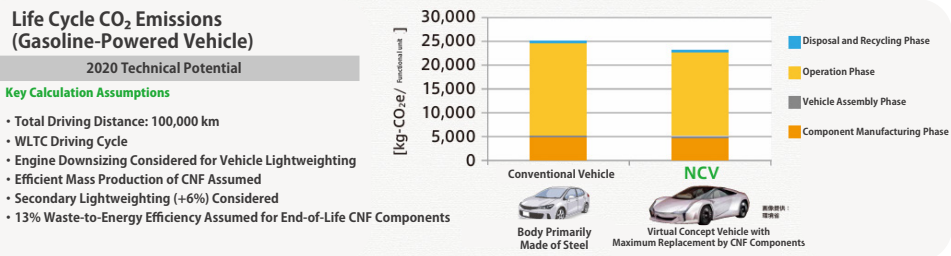
◆Key Activities

Automotive components were prototyped using CNF materials, and the components for which the manufacturing processes were developed were evaluated for their performance, including CO₂ reduction, strength, and thermal insulation.



◆Results

Evaluation and demonstration of the CO₂ reduction potential of CNF materials suitable for automotive components showed a potential reduction of 16% through vehicle lightweighting and 11% through improved fuel efficiency. These results demonstrated the potential of the Nanocellulose Vehicle (NCV).





Ministry of the Environment Nano Cellulose Promotion



We support the social implementation of CNF materials

Toward a sustainable and resilient society through the transition to a decarbonized, circular, and decentralized economy.



Are you considering a transition away from petroleum-based materials?

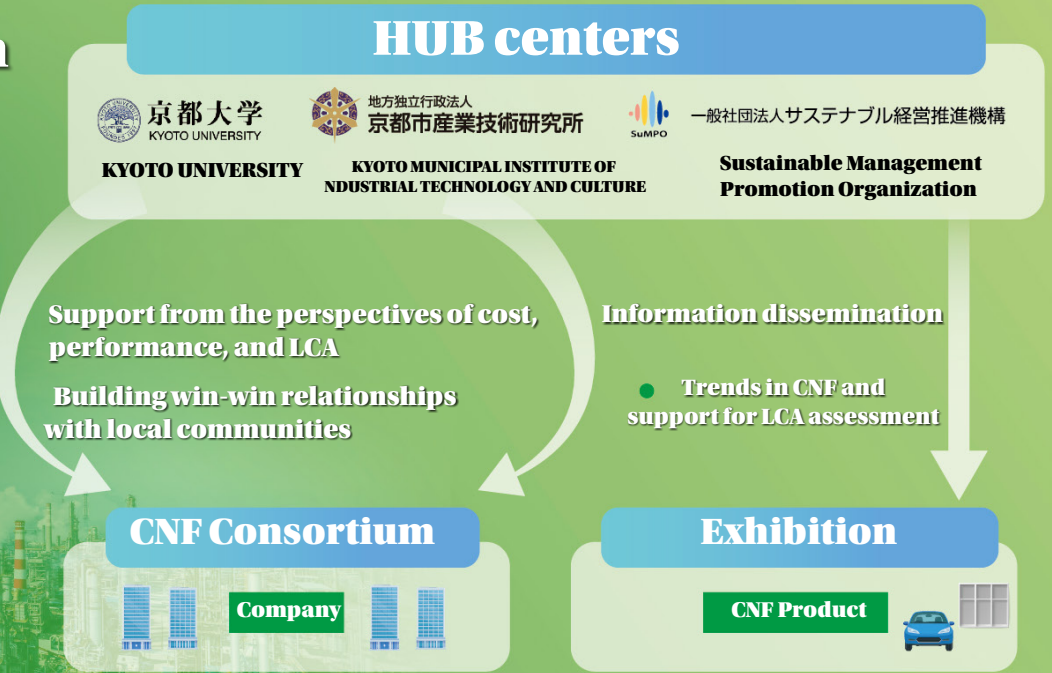
Transitioning away from petroleum-based materials is a major challenge for the future. With our extensive expertise and network, we strongly support this transition and work together toward a sustainable society.

- Looking for new products and new technologies
- Looking for the latest development status and practical applications
- Want to use environmentally friendly materials



If you are interested in CNF, please feel free to contact us.

Framework: A CNF social implementation model through collaboration with local communities

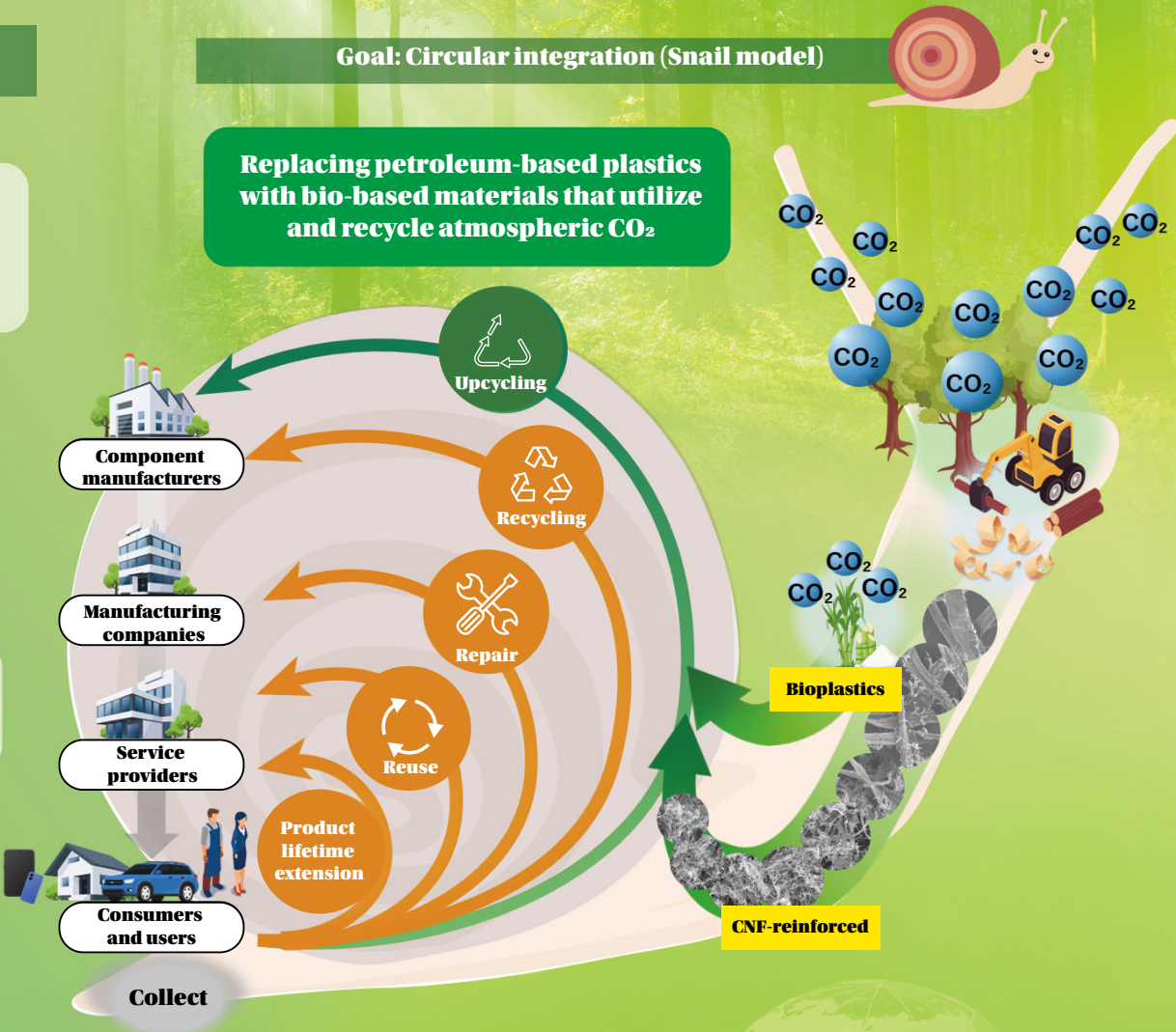


Support provided by HUB centers



Goal: Circular integration (Snail model)

Replacing petroleum-based plastics with bio-based materials that utilize and recycle atmospheric CO₂



Shall we build a sustainable and resilient economic society together



The future of high-performance plastics enabled by CNF, where just a 10% addition dramatically changes plastic performance

Please take a look at the innovative technologies enabled by CNF. By adding just 10% CNF, the stiffness of polypropylene (PP) can be doubled, aiming to reduce weight in automotive parts and decrease the use of fossil-based plastics.

We also introduce technologies that suppress thermal expansion and thermal deformation of polyvinyl chloride (PVC), enabling highly heat-resistant and high-performance window sash materials for housing.

We will show, together with concrete performance data, how CNF can transform the future of plastics.



Weight reduction and increased stiffness of automotive parts

PP + CNF =
Polypropylene

Double stiffness and a 30% reduction in fossil-based plastics

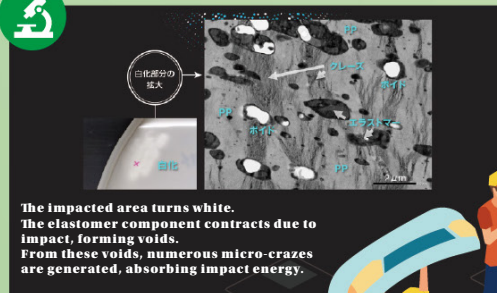
Polypropylene (PP) is widely used in automotive bumpers and interior materials. By compounding with CNF, the stiffness and dimensional stability of PP are significantly improved.

Automotive door trim



Even at MFR: 3 g/10 mm, fine details can be filled

It does not break even when struck with a hammer.



The impacted area turns white. The elastomer component contracts due to impact, forming voids. From these voids, numerous micro-crazes are generated, absorbing impact energy.



Our goal is
“One! Two! Three!”
!!!

1 One (10% addition)

Add 10% bio-based material (CNF),

2 Two (double)

Increase stiffness by a factor of two,

3 Three (30% reduction)

Improve stiffness to reduce part thickness by 20% and cut fossil-based plastic use by 30%.



Improved heat resistance and reduced thermal expansion of residential insulated window sashes

PVC + CNF =
Polyvinyl chloride

Suppresses thermal deformation and enables high-performance sashes

High thermal insulation of housing is essential for energy saving and decarbonization. CNF suppresses thermal expansion and contraction, enabling high-performance sash materials.

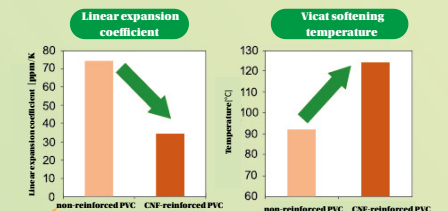
Residential insulated window sashes



Polyvinyl chloride (PVC), commonly used for conventional window frames, has issues such as large thermal expansion and contraction and reduced strength in summer. By compounding CNF with PVC, we address these challenges.

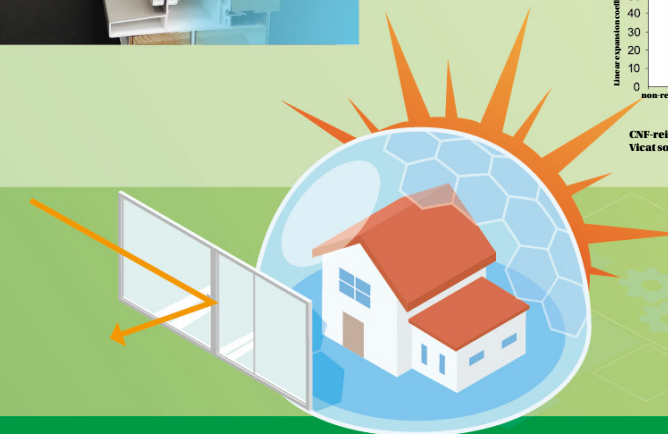
As shown in the data, CNF-reinforced PVC significantly suppresses thermal deformation, reduces the linear expansion coefficient to about half, and increases heat resistance by 30°C.

Performance data



CNF-reinforced PVC: Linear expansion coefficient reduced to about one-half
Vicat softening temperature: increased by 30°C

If you are interested in CNF, please feel free to contact us.





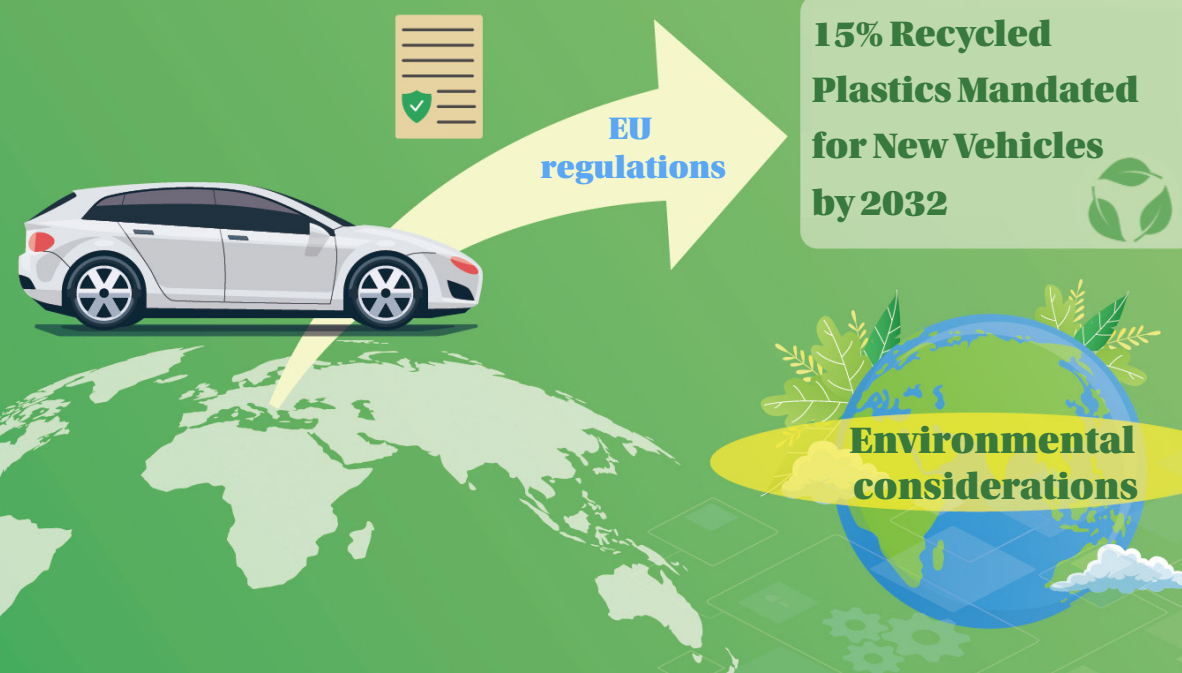
CNF & recycled plastics compliant with ELV regulations for new vehicles

By 2032, the proposed ELV regulation will require 15% of the plastics used in new vehicles to contain recycled content. We address challenges such as “reduced strength” and “performance variability” of recycled plastics by using CNF. Here, we introduce solutions in which CNF dramatically improves the performance of recycled plastics, enabling both compliance with environmental regulations and high product performance.

Challenges of recycled plastics

The ELV regulation, which mandates the use of 15% recycled materials in plastics for new vehicles by 2032, is a major challenge for automobile manufacturers. However, recycled plastics face issues such as reduced strength and increased performance variability with each recycling cycle.

We solve these problems and present a pathway to meet strict regulations.



If you are interested in CNF, please feel free to contact us.



Solutions to comply with ELV regulations

Recycled plastics + **CNF** = **Significant improvement in recycled plastic performance**

Adding just a small amount of CNF can dramatically improve the performance of recycled plastics. With a 10% addition of CNF, stiffness and strength can be increased by 1.5 times. This enables manufacturers to meet environmental regulations while maintaining stable quality and product performance. We have demonstrated that CNF-reinforced plastics can be repeatedly recycled, supporting more sustainable manufacturing.

With 10% CNF addition: 1.5× stiffness, 1.5× strength

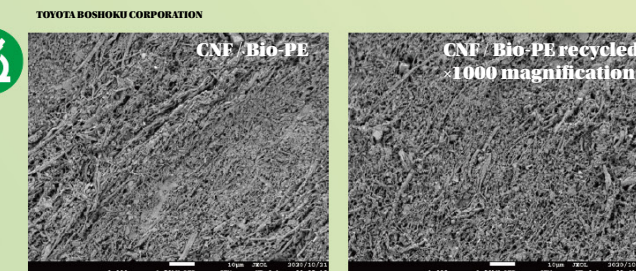
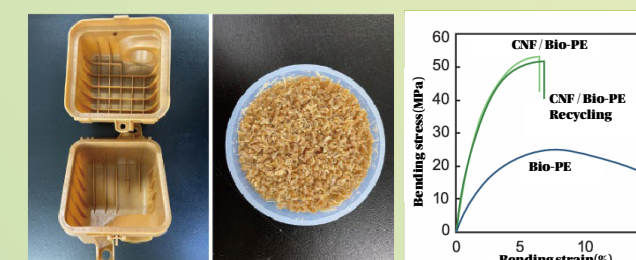
Pallet material	Flexural modulus (MPa)	Flexural strength (MPa)	Fracture strain (%)	Charpy impact strength (kJ/m ²)	MFR (g/10min)
Recycled PP	913 (9)	25.6 (0.1)	-	59 (0.9)	-
CNF2%/RePP	1040 (12)	28.7 (0.1)	-	12 (0.5)	3.8
CNF5%/RePP	1378 (11)	35.2 (0.2)	-	8.4 (0.3)	-
CNF10%/RePP	1500 (17)	37.9 (0.1)	-	5.3 (0.4)	7.3

Automotive interior material	Flexural modulus (MPa)	Flexural strength (MPa)	Fracture strain (%)	Charpy impact strength (kJ/m ²)	MFR (g/10min)
Recycled PP	1220 (35)	35.3 (0.30)	-	5.97 (0.29)	35
CNF2%/RePP	1518 (26)	39.8 (0.54)	-	4.28 (0.06)	24
CNF5%/RePP	1882 (37)	45.5 (0.25)	-	3.18 (0.42)	13
CNF10%/RePP	2687 (7)	58.6 (0.04)	6.90 (0.07)	2.40 (0.06)	4.6

NEDO / CNF Human Resource Development Program - Related Research 2022

Molding → pulverization → remolding

 **Recyclable**



Ministry of the Environment, Environmental Research and Technology Development Fund
Acetylated CNF-reinforced Bio-PE Project 2019-2020



CNF Expanding the Potential of Bioplastics

CNF, which enables both a shift away from petroleum-based plastics and enhanced product performance, has become an essential material for the future of plastics. Here, we present concrete examples in which CNF reinforcement brings new possibilities to bio-based materials, such as bio-based polyethylene (Bio-PE) that significantly reduces CO₂ emissions by utilizing plant-derived carbon, and biodegradable plastics that maintain strength while promoting degradation..



New materials that dramatically
improve environmental performance

Bio-PE + **CNF** = Significant CO₂ reduction
through the power of plants

Biomass polyethylene

By combining plant-derived biomass polyethylene (Bio-PE) with CNF, high-performance plastics with low CO₂ emissions are developed. This approach aims to replace plastics derived from fossil resources.



Increased degradation speed while maintaining strength

Biodegradable plastics + **CNF**

= Promotes degradation while maintaining strength
during the degradation process

By compounding CNF with biodegradable plastics, the range of applications for biodegradable plastics expands, enabling new manufacturing that achieves both environmental performance and product performance.

CNF-reinforced Bio-PE products, prototypes



Number tag (Kamiyama, Ltd)



Rice bowl (UNION SANGYOU CO., LTD)

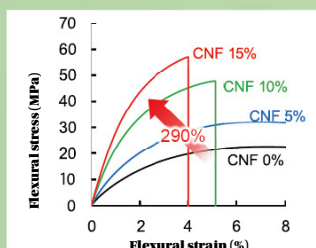
Performance data

Flexural modulus

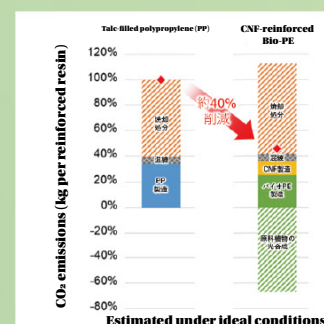
CNF 0% 1110 MPa → 290% UP → CNF 15% 3220 MPa

Heat deflection temperature (1.80 MPa)

CNF 0% 47.1 °C → 61.2 °C UP → CNF 15% 108.3 °C



CO₂ emission reduction potential



Compared with talc-filled polypropylene (PP), CNF-reinforced Bio-PE can reduce CO₂ emissions by approximately 40%.

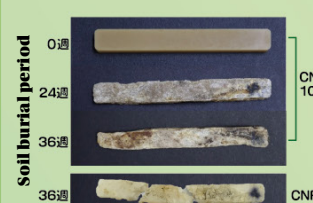
Toward environmentally
oriented product branding

Performance data

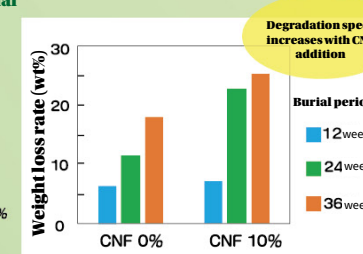
<Flexural modulus and biodegradability of PBS with 10% CNF>

CNF 0% 270 MPa → 540% UP → CNF 10% 1450 MPa → 24週 1500 MPa → 36週 780 MPa

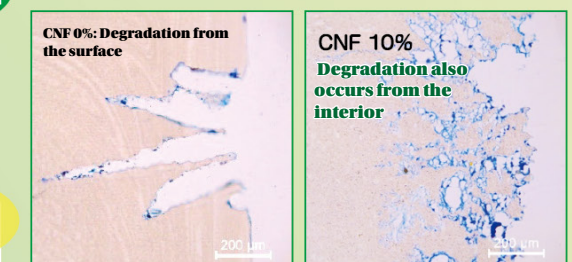
Appearance before and after soil burial



Weight change due to soil burial



Optical microscope images



※Microorganisms observed after blue staining

Materials with 10% CNF addition show approximately three times higher flexural modulus compared to materials without CNF. Furthermore, even after soil burial, CNF functions as a structural framework, maintaining strength for a certain period while accelerating degradation.

If you are interested in CNF, please feel free to contact us.





Innovation in foamed plastics reinforced with CNF that achieve both weight reduction and high strength

We introduce technologies in which CNF solves challenges of foamed plastics and creates new value. By compounding CNF, increased foaming ratio, finer and more uniform cells, and suppression of shrinkage are achieved. This enables both weight reduction and higher modulus, and applications are progressing in specific products such as running shoes and stackable containers.



Achieves both weight reduction and strength improvement

Foamed plastics

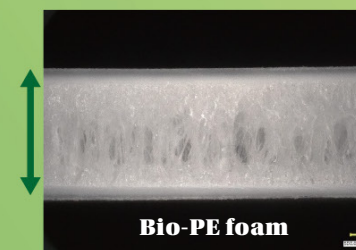
+ CNF =

Refines cells and improves moldability and strength

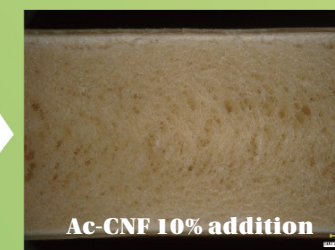
Foamed plastics are highly effective for material reduction and weight reduction of components, but they generally have the issue of decreased strength. We solved this problem by compounding CNF. By adding CNF, the cells of the foam become finer and more uniform, improving strength. It is also possible to suppress shrinkage while improving moldability.

As a result, CNF foamed plastics expand their potential as new lightweight yet high-strength materials for automotive parts, sports goods, cushioning materials, and packaging materials.

The maximum foaming ratio improved

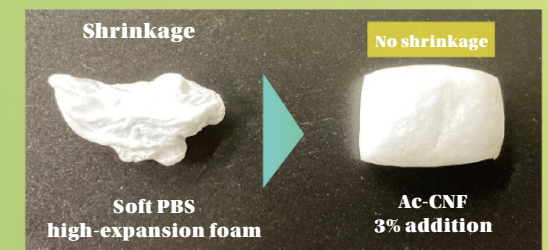


3× foamed

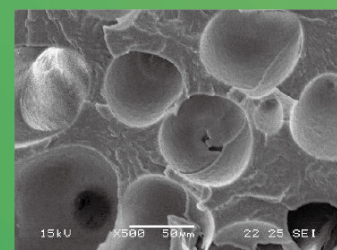


5× foamed

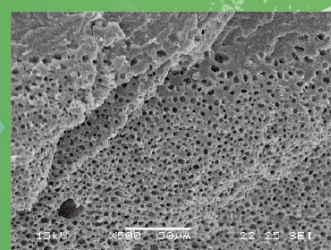
Shrinkage suppression



Cell refinement and uniformity



Polyamide(PA6)



Ac-CNF10% addition

Lightweight and high modulus

Performance data

Material	Molding method	Density (g/cm ³)	Modulus (GPa)
PA6	Non-foamed	1.13	2.47
Ac-CNF3%	2× foamed	0.75	2.56
Ac-CNF5%	2× foamed	0.72	2.81
Ac-CNF10%	2× foamed	0.71	3.41
	3× foamed	0.59	2.60

With Ac- (acetylated) CNF addition, lower density and higher modulus compared to non-foamed PA6

Practical examples

Running shoes



Used in midsoles

ASICS Corporation
achieving both weight reduction and durability

Stack-Up containers



Yoshikawa Kuni Kogyo Co., Ltd.
approximately 8% CO₂ reduction

If you are interested in CNF, please feel free to contact us.



Next-Generation Manufacturing: 3D Fabrication Empowered by CNF

We are developing innovative technology to fabricate CNF reinforced plastics using 3D printers. Because this technology does not require molds, it enables fine-tuning of part design, the production of complex geometries, and small-lot manufacturing. Furthermore, by imparting CNF's excellent properties—lightweight, high strength, and recyclability, it redefines conventional manufacturing practices.

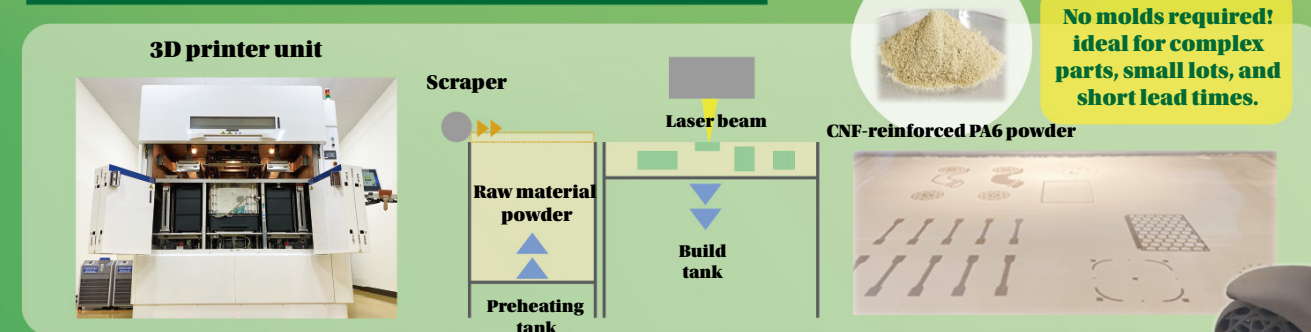


CNF transforms the manufacturing process

3D printing + **CNF** = **Mold-free, rapid production of complex and high-strength components**

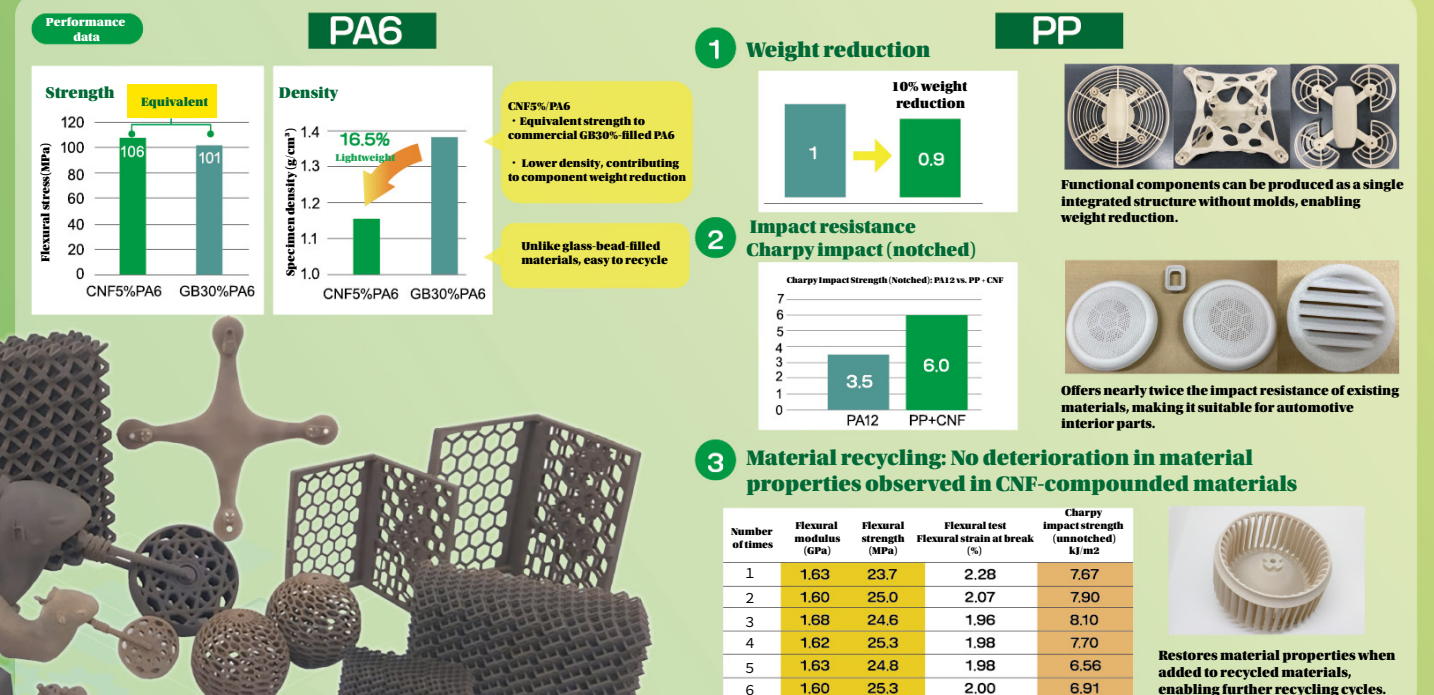
This innovative technology maximizes the advantages of mold-free 3D printing. It enables the direct fabrication of parts with complex geometries and internal structures from digital design data. This capability facilitates design refinement, high-mix/low-volume production, and shorter lead times. By integrating CNF with 3D printing, we introduce a new approach to manufacturing that frees designers and engineers from conventional production constraints.

PBF: Powder Bed Fusion



Achieves both high performance and recyclability

CNF reinforced 3D printing materials not only eliminate the need for molds but also offer excellent physical properties. Adding CNF reduces material density, enabling a 10% reduction in part weight. Moreover, while achieving strength comparable to commercially available glass-bead-filled materials, they offer a significant advantage in recyclability. CNF is a next-generation material that delivers both high performance and sustainability.



If you are interested in CNF, please feel free to contact us.



A Future Vehicle Enabled by CNF Nano Cellulose Vehicle (NCV)

This introduces the achievements of the Nano Cellulose Vehicle (NCV) project led by the Ministry of the Environment. It is a fully functional prototype developed over four years using as much CNF as possible and exhibited at the 2019 Tokyo Motor Show. By applying CNF, the vehicle achieved remarkable results: a 16% reduction in weight and an 11% improvement in fuel efficiency at 100 km/h compared with a typical vehicle. Plant-derived CNF demonstrates the potential to significantly transform the future of automobiles.

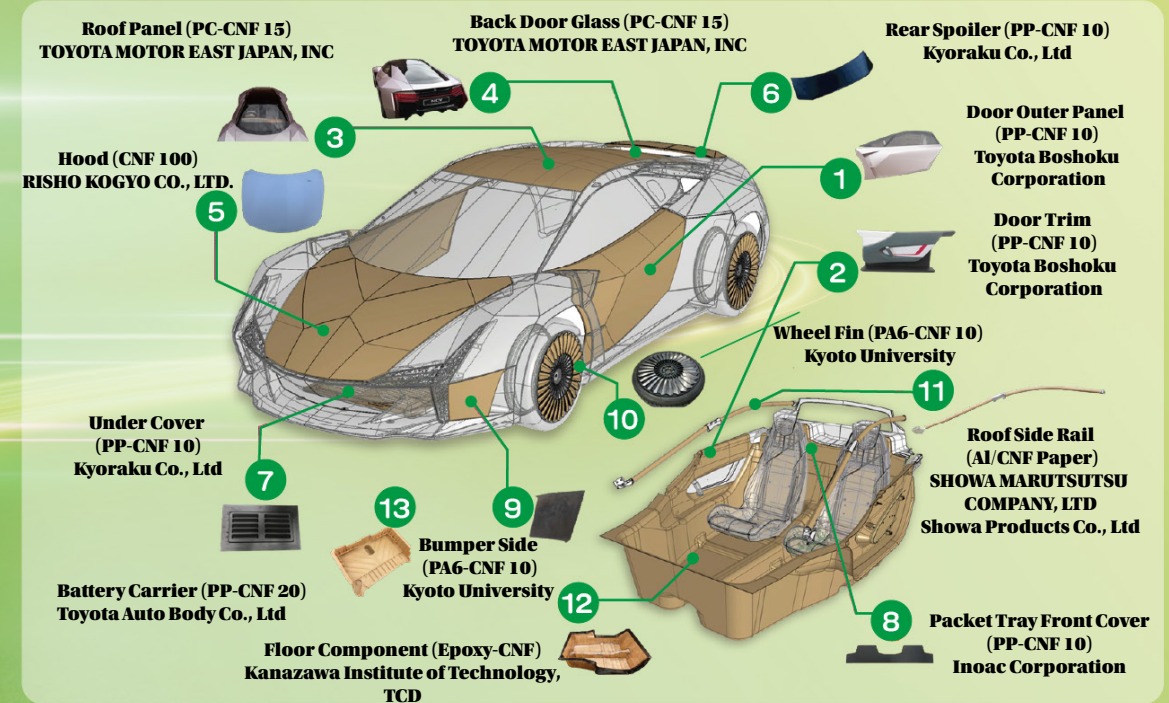


The NCV project applied CNF to 13 vehicle components, achieving a 16% weight reduction and an 11% improvement in fuel efficiency. This is a groundbreaking achievement showing that plant-derived CNF can reduce vehicle weight and improve future environmental performance.

Toward Carbon Neutrality Future Performance Proven by CNF

Ministry of the Environment NCV Project FY 2016–FY 2019
Consortium Established: October 26, 2016

Challenging weight reduction with plant-derived next-generation CNF materials



Co-creation Innovation Driven by the Collaboration of 22 Industry, Academic, and Government Partners

Ministry of the Environment Nano Cellulose Promotion



Kyoto Process 4th Generation – Shaping the Future of CNF with High-Efficiency Reactive Processing –

Toward a society that leverages the blessings of forest resources to strengthen industrial competitiveness and create environmental value

Cellulose nanofiber (CNF) is a lightweight and high strength material derived from wood. The “Kyoto Process 4th Generation,” developed by Kyoto University, employs a new method in which pulp is directly kneaded with resin for modification and nano fibrillation. This approach reduces the conventional four manufacturing steps to two, enabling low cost, low CO₂, and large-scale production. Wider adoption of CNF produced through this technology will increase CO₂ absorption and storage as a renewable forest resource. Products made with CNF can be made lighter, and it has been shown, for example, to improve fuel efficiency in automobiles. In addition, reducing the use of fossil-resource-based resins contributes to CO₂ reduction across the entire product life cycle.

NCP Supports LCA

Case Examples of Product Commercialization Enabled by LCA Evaluation

Yoshikawa Kuni Kogyo Co., Ltd.
“Stack-Up Container”
Effect of Weight Reduction on CO₂ Emissions



VeSS CO.,LTD.
“Brush / Comb”
CO₂ Reduction through
Resin Replacement (ABS → PP)



The Sustainable Circular System Enabled by CNF

From Forest to Products — The 4th-Generation Process Flow



Conventional Process



Reinforced resin manufacturing shortened from

4 steps to 2

enabling low cost, low CO₂, mass production processing.

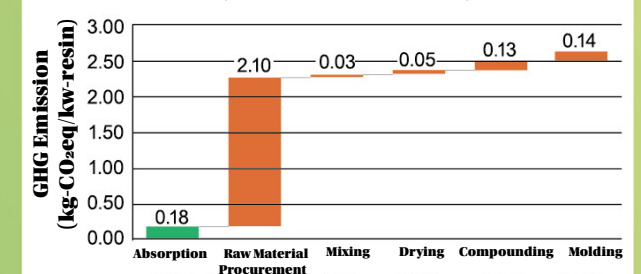
Kyoto Process 4th Generation



From Forest to Products CNF's Life Cycle CO₂ Reduction Potential

性能データ

Results of GHG Emission Estimates (4th Generation CNF)



The GHG emissions of the resin produced through this technology (hereafter referred to as 4th-generation CNF) were estimated as shown above. Because this CNF is made from forest resources that absorb CO₂, it contributes to GHG reduction through CO₂ absorption and sequestration. Beyond satisfying the required performance of end users and final products, it also allows for assertions of GHG reductions based on the proportion of CNF blended. The “Kyoto Process 4th Generation” is recognized as an emerging material technology that supports a sustainable society.

If you are interested in CNF, please feel free to contact us.