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Development of Biomanufacturing Technologies for the Realization of Sustainable Society

1. Introduction

Sustainability refers to a term that combines “sustain” and “ability,” and indicates the state in which the systems of the Earth and society maintain their functions and continue to operate into the future. Moreover, in order to realize a sustainable society, it is considered important to build systems and processes in which the three pillars of “environmental protection,” “social development,” and “economic growth” develop in a balanced way while mutually influencing each other.

Biomanufacturing technology is attracting attention as one of the approaches to realize this sustainable society. In principle, biomanufacturing is a cutting-edge technological innovation that combines biotechnology, such as synthetic biology and genome editing, with rapidly developing digital technologies like IoT and AI. It utilizes technologies that enable more efficient genetic modification to produce useful substances from the cells of microorganisms, animals, and plants. This technology is fundamentally based on the biological mechanisms found in nature. However, in addition to the substances that microorganisms originally produce within their cells for their own purposes, it employs techniques such as conferring additional substance-producing capabilities upon microorganisms using genome editing, enhancing or disabling the functions of microbial enzymes, and other similar methods. These approaches enable the efficient mass production of target substances from raw materials. In other words, it is a new approach that applies biological operations to industrial manufacturing processes and has the following characteristics and advantages.

Biological manufacturing has the advantage of enabling high-yield synthesis of compounds that are difficult to produce through chemical processes, by using highly specific bioprocesses with microbial enzymes, thereby reducing the generation of byproducts. Various enzymes in microbial cells collaborate to facilitate multi-step synthesis reactions, making them ideal for synthesizing substances with complex structures and high carbon numbers. Biomanufacturing has been primarily used in the biopharmaceuticals and food industries. However, as biotechnology advances rapidly, its application in a variety of industrial fields, including fuels, chemicals, and textile materials, is on the rise.

The greatest advantage of biomanufacturing is that it not only drives innovation in industrial activities, such as the development of new products and the transformation of manufacturing processes, but also makes it possible to simultaneously address global social challenges like climate change, food shortages, resource scarcity, and marine pollution. In chemical manufacturing, which is at the center of current industrial activities, it often requires reactions at high temperatures and high pressures that have a significant environmental impact. In contrast, in biomanufacturing reactions can be carried out at room temperature and pressure, which is expected to reduce CO_2 emissions compared to chemical processes. Biomanufacturing can also utilize bio-based resources as raw materials, such as biomass, which absorb CO_2 during its growth process. Unlike chemical processes that depend on fossil resources like petroleum, this method considerably reduces new emission of CO_2 that affects climate change. Furthermore, in cutting-edge biomanufacturing, it is becoming increasingly possible to recycle waste derived from chemical products—which previously could only be disposed of through environmentally burdensome methods such as landfilling or incineration—and the CO_2 generated from incinerating these wastes, into resources needed for industrial activities, such as fuels (biofuels), new chemicals (green chemicals), or as starting materials for these products.

In this way, biomanufacturing is important as a technology for achieving carbon neutrality by moving away from petroleum resources and using manufacturing methods that do not put a burden on the environment. In addition, biomanufacturing is important as a technology for addressing social issues such as marine pollution and for building a circular economy through the effective use of unused resources derived from waste, thereby preserving the global environment for the future. Furthermore, the technological innovations in biomanufacturing will enhance brand strength and international recognition, supporting the next generation of industrial infrastructure, attracting investment, and becoming the economic foundation that sustains the future. It is not an exaggeration to say that this technology should be developed to promote a balanced advancement of “environmental protection” and “economic development,” which are essential for realizing a sustainable society. RITE has long focused on biotechnology manufacturing and has actively worked on developing core technologies and other elements to lay the foundation for industrial applications.

This overview will first introduce RITE's core technologies, including the "RITE Bioprocess"[*1] and

"Smart Cell Creation Technology." Next, it will introduce the status of technological development efforts in various national projects involving RITE, particularly the initiatives in foundational technology development in the "bio × digital" technology field at "RITE Biomanufacturing Center," which was completed in November 2025. Finally, it will discuss efforts toward commercialization aimed at social implementation and future prospects.

2. The Core Technologies of RITE

2.1. "RITE Bioprocess"

RITE has been focusing on the value of Corynebacterium, which are representative industrial microorganisms with unparalleled high production capabilities, and has been engaging in developing core technologies for their use. As part of RITE's research, it was discovered that "Corynebacteria exhibit the phenomenon where their growth is inhibited under anaerobic conditions, while the metabolic functions necessary for substance production are maintained, allowing them to efficiently produce organic acids and other compounds from sugars." Based on this phenomenon, RITE established the RITE- proprietary technology, growth-independent bioprocess known as the "RITE Bioprocess." "RITE Bioprocess" is one of the most crucial core technologies for promoting the social implementation of biomanufacturing. (Fig. 1). Below are its three main features.

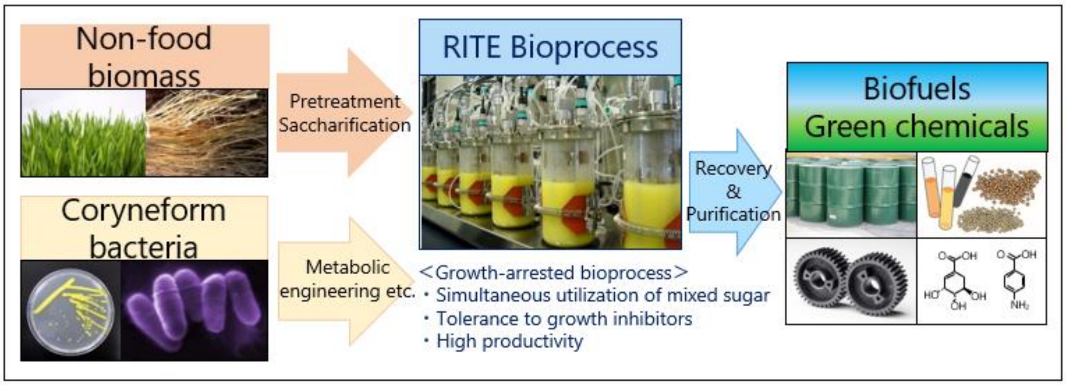

Fig. 1 Biomanufacturing using the "RITE Bioprocess"

Feature 1: Growth-arrested bioprocess

In nature, fermentation typically requires microorganisms to grow while producing substances. However, RITE has established a " growth-arrested bioprocess," in which cell growth stops under certain anaerobic conditions or aerobic conditions with essential growth factors removed, while the production of the desired substance continues (Fig. 2). " Growth-arrested bioprocess" are technologies that achieve productivity equal to or greater than chemical processes, because all the nutrients and energy that are conventionally consumed for microbial growth are used solely for the production of the target substance.

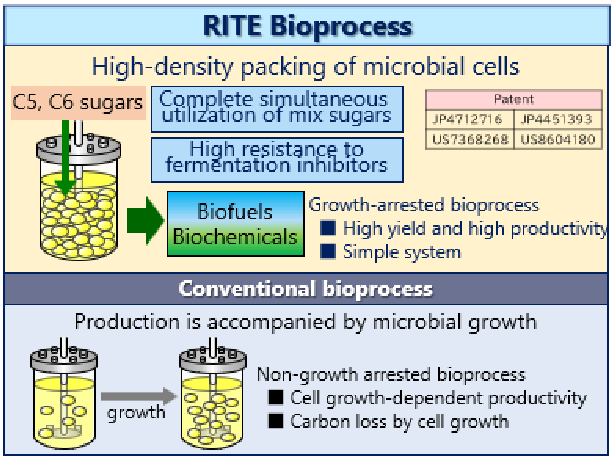

Fig. 2 Feature 1 of the "RITE Bioprocess" (Growth-arrested bioprocess)

Feature 2: High tolerance to fermentation inhibitors

In biomanufacturing, raw materials such as biomass or waste-derived unused resources often contain chemicals that inhibit microbial growth. Also, the target substances produced by microorganisms can themselves inhibit growth or damage the microorganisms. It limits the types of substances that can be produced through fermentation. On the other hand, "RITE Bioprocess," is a production system that does not involve microbial growth, making it highly resistant to various fermentation inhibitors (Fig. 3).

This allows high productivity even with previously unusable raw materials and for various substances that were difficult to produce through fermentation.

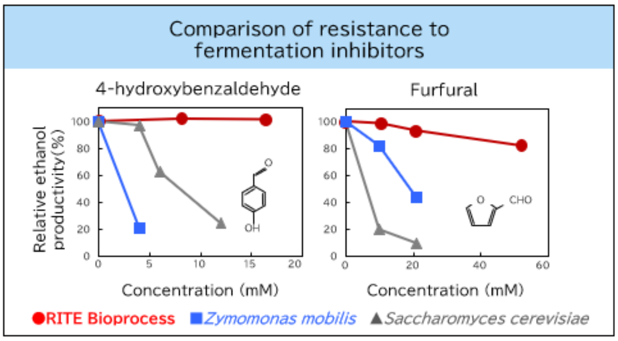

Fig. 3 Feature 2 of the "RITE Bioprocess" [*1]

(High tolerance to fermentation inhibitors)

Feature 3: Complete simultaneous use of mixed C5 and C6 sugars

Non-edible cellulose-based biomass is a common raw material in the biomanufacturing sector. This biomass contains a mixture of C6 sugars, such as glucose, and C5 sugars, such as xylose and arabinose. Microorganisms typically favor C6 sugars utilization for substance production, which reduces C5 sugar utilization efficiency. At RITE, new C5 sugar metabolic and transporter genes were introduced into microorganisms to increase the utilization rate of C5 sugars to the same level as C6 sugars (Fig. 4). The complete simultaneous utilization technology of C5 and C6 sugars is an essential core technology in biomanufacturing, enabling maximum production efficiency while minimizing waste of non-edible biomass raw materials.

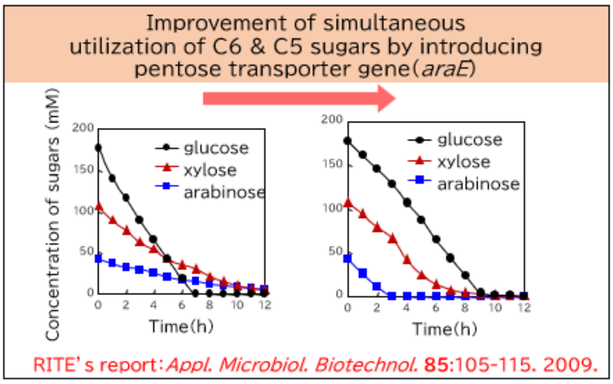

Fig. 4 Feature 3 of the "RITE Bioprocess" [*1]

(Simultaneous usage of mixed sugars)

2.2. Smart Cell Creation Technologies

Smart cells are biological cells whose functions and metabolism have been precisely designed and controlled through genetic modification to maximize its capacity for substance production. The collective set of digital technologies used to analyze biological information and design ideal cells, together with the biotechnologies that implement these designs in actual production strains, are referred to as Smart Cell Creation Technologies. These technologies enable the efficient breeding and development of smart cells.

Through proof-of-concept studies in which target compounds were defined, RITE has successfully developed a suite of smart cell creation technologies and demonstrated their effectiveness (Fig. 5). Going forward, RITE aims to apply these technologies to a wide range of fields, including biofuels and green chemicals, while continuing to improve and refine the technologies.

In addition, a project is currently underway to develop Industrial Smart Cell Creation Technologies with the objective of addressing the challenges associated with practical implementation, thereby linking smart cell creation technologies and the smart cells generated by them to industrial applications. Details of this project are explained in Section 3.5, Research and development of industrial smart cell.

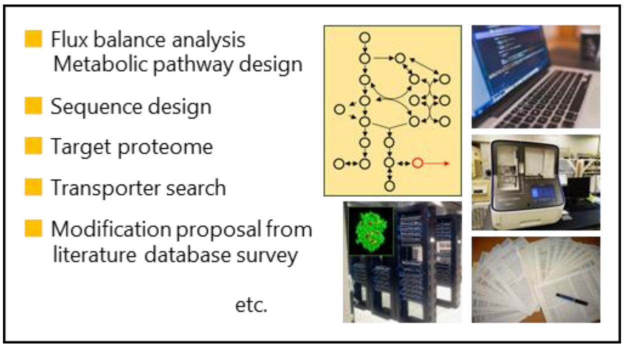

Fig. 5 Smart Cell Creation Technologies

2.3. Substances Produced by the "RITE Bioprocess"

RITE has achieved high production levels for various substances, as shown in Fig. 6. Many of these compounds have reached exceptional productivity levels. In the biofuel domain, RITE has expanded its lineup to include not only ethanol and biohydrogen but also butanol and high-performance bio-jet fuels. Meanwhile, our green chemicals focus has broadened to include L-lactic acid, D-lactic acid, amino acids, and high-functional chemicals such as aromatic compounds.

Aromatic compounds, which are key industrial chemicals important as raw materials for polymers and other products, are also valuable high-added-value compounds used as raw materials for pharmaceuticals, functional nutritional ingredients, fragrances, cosmetics, and more. Currently, aromatic compounds are primarily manufactured from petroleum, with only a small fraction derived from natural plants.

However, from reducing petroleum dependency, environmental conservation, and ensuring productivity perspectives, biomanufacturing is eagerly anticipated. In nature, microbes biosynthesize a variety of aromatic compounds, such as phenylalanine, tyrosine, tryptophan, folic acid (vitamin B9), and coenzyme Q. All these compounds are derived from a metabolic pathway known as the shikimate pathway, which is present in microorganisms.

By employing biomanufacturing technology to the fullest extent, designing the metabolic pathway of Corynebacteria at will, and utilizing non-edible biomass, RITE has established a high-performance bioprocess capable of producing shikimic acid (the raw material for influenza medicine Tamiflu), 4-aminobenzoic acid (promising raw material for high-performance polymers), and other raw materials for polymers, pharmaceuticals, cosmetics, and fragrances (vanillin).

Biofuels	Green chemicals
■ Gasoline additives ・Ethanol * ■ Bio-jet fuels ・Isobutanol * ・n-Butanol * ・C9-C15 Saturated hydrocarbon + Aromatics ■ Biohydrogen	■ Aromatics ・Shikimic acid (Anti-influenza drug; Tamiflu raw materials) ・Phenol * (Phenolic resins, Polycarbonates) ・4-Hydroxybenzoic acid * (Polymer raw materials) ・Aniline * (Natural resource tire (Age resistor)) ・4-Aminobenzoic acid * (Pharmaceutical raw materials) ・Protocatechuic acid * (Cosmetic raw materials) ■ Organic acids ・D-Lactate *, L-Lactate * (Stereo-complex PLA) ・Succinate * ■ Amino acids ・Alanine (Chelators) ・Valine (Next-generation feed-use amino acids) ・Tryptophan (Next-generation feed-use amino acids) ■ Alcohols ・Isopropanol (Propylene raw materials) ・Xylitol (Sweetener)

* : Polymer raw materials Red character : World's highest productivity achieved

Fig. 6 Substances produced using the "RITE Bioprocess"

Technologies Required for Development		Bio-manufacturing Technologies Functional Analysis, Design, Expression and Regulation, Strain Breeding, Strain Improvement
Bio-chemicals	Resources Biomass CO_2	**3.1 Biomanufacturing Platform** Development of Bio-upcycling Technology to Produce Useful Chemicals from Unused Raw Materials
		3.2 Biomanufacturing (CO_2) Commercialization of High Value-Added Chemical Products Using CO_2 as a Raw Material through Biomanufacturing Technology
		3.3 Biomanufacturing (Fiber) Establishment of Innovative Bio-Upcycling Technology Aiming to Realize Resource Circulation from Fiber to Fiber
		3.4 Marine biodegradable plastic Research and Development of Marine Degradable Multi-lock Biopolymers from Inedible Biomass
		3.5 Industrial Smart Cell Research and Development of Data-driven Integrated Bioproduction Management System
Biofuels		**3.6 Biohydrogen** Development of Biofuel Production Technologies

Fig. 7 Overview of participating national projects and new technologies required for development

3. Fundamental Technology Development (National Projects)

The Japanese government is currently providing substantial support for biomanufacturing, aiming to achieve sustainable manufacturing through economic growth and resource self-sufficiency, while simultaneously pursuing innovation that addresses social challenges. Fig. 7 summarizes the national projects in which RITE participates, as well as the biomanufacturing technologies that RITE is responsible for developing.

We are involved in the NEDO Biomanufacturing Revolution Promotion Fund Project and the NEDO Green Innovation Fund Project and , which is bio-upcycling technologies to produce useful chemicals from unused resources (Biomanufacturing Platform; Sections 3.1) and to develop biomanufacturing technologies for high-performance adhesive raw materials from CO_2 (Biomanufacturing (CO_2); Sections 3.2), and also, development of biotechnology for Recycling Waste Fibers (Biomanufacturing (Fiber); Sections 3.3).

Furthermore, as a participant in the Moonshot R&D Program, we are also pursuing the research and development of Multi-Lock Marine Biodegradable Plastics (Section 3.4) made from non-edible biomass as a raw material. In addition, we participate in JST's COI-NEXT (Carbon Farming Hub Challenging the Limits of Carbon Negativity) Project, and engage in research and development related to "Biohydrogen (Section 3.6). Below, we describe the status of RITE's involvement in national projects for the fiscal year 2026.

3.1. Biomanufacturing platform "Development of bio-upcycling technology to produce useful chemicals from unused raw materials"

NEDO "Biomanufacturing Revolution Promotion Project" Phase 1, launched in FY2023[*2]

This project aims to build a value chain for bio-based manufacturing that utilizes a diverse range of feedstocks to produce a wide variety of products. In this initiative, RITE, together with Takasago International Corporation and Teijin Limited, has identified key challenges and has launched research and development activities to address them.

As part of the technology development, RITE is creating a metabolism model specifically designed for Corynebacterium species, along with computational methods for metabolic simulation based on the model. By incorporating detailed culture data, these simulations can more closely approximate actual production conditions than conventional approaches. Although metabolome analysis, which comprehensively measures and analyzes small-molecule metabolites present in cells, can yield extremely valuable information, it is also a technique in which obtaining high-quality data is often difficult. By improving this analytical method and tailoring it specifically to Corynebacterium strains used at RITE - while also semi-automating the workflow - we succeeded in enabling more accurate metabolome analysis. This advancement now allows the entire process, from sampling to data analysis, to be completed within RITE.

In addition, following the efforts made last year, RITE has continued to develop a database containing information on the composition of underutilized resources and the production-inhibiting effects of products (cytotoxicity caused by compounds).

Using the collected data, we have implemented enhanced functions such as applying machine learning to identify components that are important for cell growth and product formation. By integrating these strain engineering technologies, RITE aims to strengthen its competitiveness in microbial breeding and to serve as a “microbial development platform” that provides production strains and manufacturing technologies to companies seeking to enter the biomanufacturing industry (Fig. 8). To serve as a hub for these efforts, RITE has established a new research facility, the “RITE Biomanufacturing Center.” The center integrates both Dry functions—computational design and information analysis—and Wet functions, including biological experiments, strain engineering, cultivation, and analysis. This integrated environment is being developed to enable more efficient strain development for biomanufacturing. Furthermore, in the future, to ensure that short-term visitors from partner companies can securely obtain cultivation data and other information needed for development, RITE plans to strengthen security measures and enhance its hosting environment. RITE and each company aim to strengthen Japan's industrial competitiveness and address social issues through the “RITE Bio Manufacturing Center.”

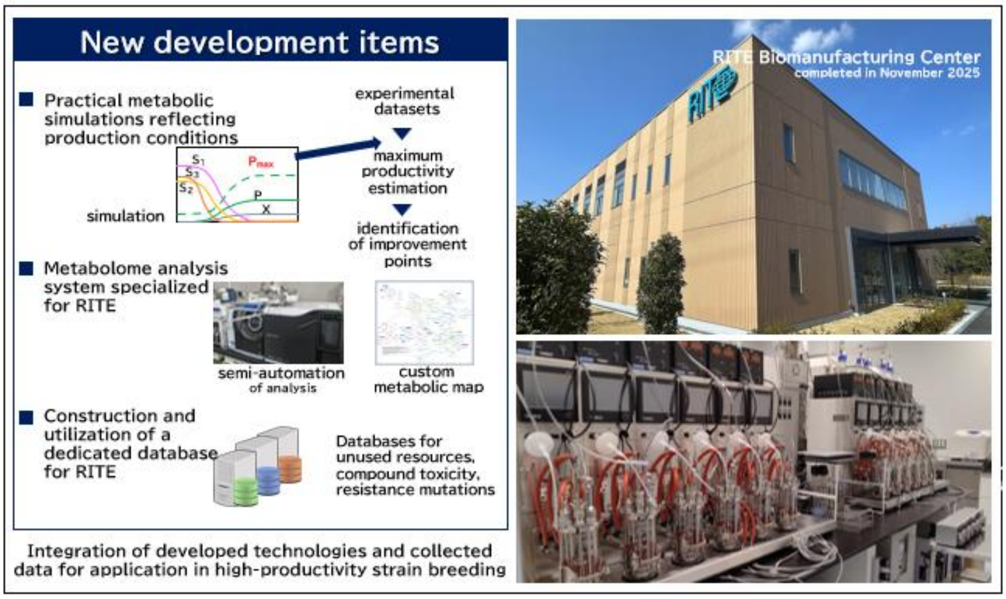

Fig. 8 A base functioning as a microbial development platform

3.2. Biomanufacturing (CO_2) "Productization of High Value-Added Chemicals Products Using CO_2 as a Raw Material through Biomanufacturing Technology" *2

This project aims to contribute to the realization of "carbon neutrality by 2050" by developing and deploying novel biomanufacturing products that use CO_2 as a raw material. This breakthrough also seeks to reform the industrial structure by embracing CO_2 as a resource.

In this respect, RITE, together with Sekisui Chemical Co., Ltd., started this project in FY2023 and are currently undertaking it (project period: 8 years from FY2023 to FY2030). Fig. 9 displays the research and development conducted in this collaboration. In this project, Sekisui Chemical utilized chemical catalysts to convert CO_2 efficiently into CO with high energy levels, making it easier to use by organisms. RITE then converts CO into polymer raw materials for epoxy resin by using a bioprocess using CO-utilizing bacteria. The resulting polymer raw materials are dimerized and epoxidized by Sekisui Chemical to produce high-value-added heat-resistant adhesives, which are used in the electronics field, including smartphones, aircraft, and automobiles, to bind special components that require heat resistance. After use, these adhesives can be combusted into CO_2, thus closing the resource recycling loop.

RITE is harnessing the smart cell technology and bioproduction technology it has cultivated to date to address the most important issues: (1) development of bacteria strains able to convert CO to polymer raw materials (such as developing genetic recombination tools for CO-utilizing bacteria and constructing producer strains of the intermediates and the polymer raw materials from CO), and (2) developing bioprocesses for the target polymer (including process design, optimization of culture conditions, and continuous process development) on a laboratory scale in general.

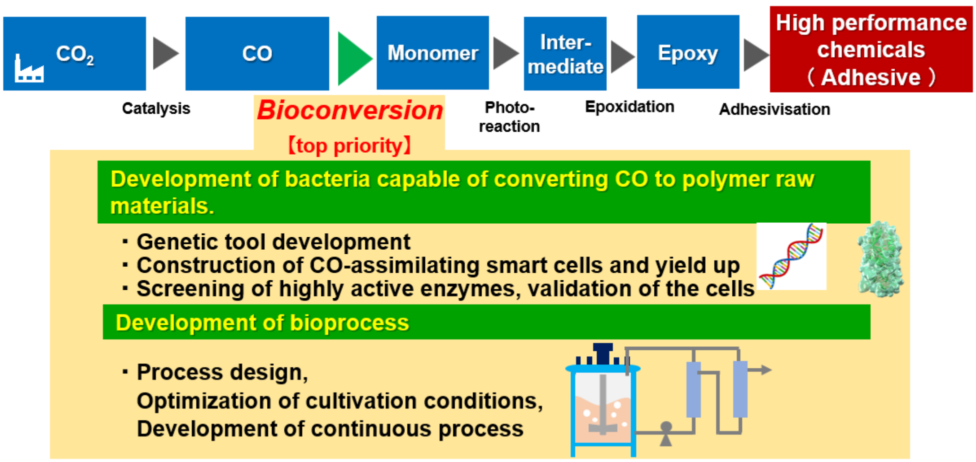

Fig. 9 High-value-added chemical products made from CO_2 by biomanufacturing technology

3.3. Biomanufacturing (Fiber) "Research, Development, and Demonstration for the Realization of Fiber-to-Fiber Resource Circulation /Development, Demonstration, and Advancement of Innovative Bio-upcycling Technologies Based on Bio-separation and Bio-conversion for the Realization of Fiber-to-Fiber Resource Circulation"

Commencing in FY2025, this project aims to establish the world's first "fiber-to-fiber resource circulation system" through a strategic partnership between RITE and five of Japan's leading textile companies: Teijin Frontier Co., Ltd., Kurabo Industries Ltd., Toray Industries, Inc., Nisshinbo Textile Inc., and The Japan Wool Textile Co., Ltd. By integrating mechanical, chemical, and biological technologies, this initiative addresses the recycling of composite fiber garments—which were previously incinerated or landfilled—by enabling the simultaneous reclamation of both synthetic and natural fibers.

Most clothing is made of composite materials consisting of synthetic and natural fibers. In order to recycle them, it is necessary to separate the composite materials into single materials. However, with conventional technology, some materials are damaged during the separation process, so recycling has been limited. Aiming to solve this issue, RITE is developing pretreatment technologies utilizing mechanical and chemical pretreatment methods, selective bio-separation using enzymes and microorganisms, and bioconversion techniques that transform materials into high-value-added textile precursors. By combining these technologies, RITE promotes the development of technologies to selectively separate synthetic fibers, such as polyethylene terephthalate (PET), from composite fiber materials and recover natural fibers (cotton, wool) as single fiber materials. In addition, for synthetic fibers such as PET, we aim to establish innovative technologies to reuse chemicals that become fiber raw materials, and for natural fibers, to reuse them as regenerated fibers (project period: 8 years from FY 2025 to FY 2032).

In collaboration with our industrial partners, RITE is focused on three primary technical pillars: the discovery and enhancement of high-performance enzymes and microbial strains capable of selectively degrading PET under mild conditions without compromising the physical properties of natural fibers; the engineering of strains to convert PET degradation products into value-added chemical raw materials; and the establishment of an integrated bioprocess that harmonizes these stages of degradation, separation, and production.

Looking ahead, RITE intends to accelerate these innovations by constructing a comprehensive database of enzymes for various synthetic fibers, implementing automated robotics to expedite enzyme screening and strain breeding, and establishing advanced analytical techniques for process evaluation and fiber property characterization. By equipping facilities for bench-scale testing and consolidating these core technologies, RITE aims to develop a sophisticated "Textile Resource Recovery Platform" that serves as a cornerstone for a sustainable textile industry.

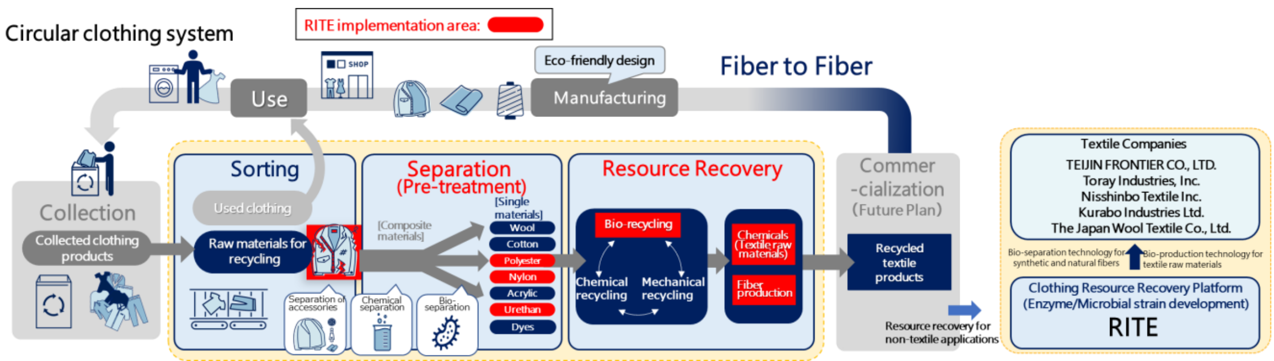

Fig. 10 RITE's role in establishing the fiber-to-fiber resource circulation system

(PET degradation, natural fiber separation, and upcycling of PET metabolites into textile raw materials)

3.4. Marine biodegradable plastic "Research and Development of Marine Degradable Multi-lock Biopolymer from Inedible Biomass" *2

In this project, research and development are being conducted to introduce a "multi-lock mechanism" in order to achieve both toughness and degradability in plastics (project period: 10 years from FY2020 to FY2029). Multi-lock mechanism is a mechanism that prevents degradation by maintaining the durability and toughness inherent in plastics during use, but when accidentally dispersed into the marine environment, the polymer bonds break only when multiple stimuli such as light, heat, oxygen, water, enzymes, microorganisms, and catalysts are applied simultaneously, triggering the decomposition process and enabling rapid, on-demand degradation.

The products targeted for commercialization in this project include tires and agricultural materials that generate fine particulate matter during use, as well as fishing nets and fishing gear that contribute to ghost fishing. Once released into the marine environment, these items are extremely difficult to recover, raising serious concerns regarding their potential adverse impacts on marine ecosystems and the broader environment (Fig. 11).

By FY2025, RITE developed technology that enables artificially control of the timing of multi-locked plastics degradation initiation. This includes development of new technology utilizing degradative enzymes. First, electrostatically binding the thermostable plastic-degrading enzyme to a biodegradable carrier notably improved its thermostability. We added the enzyme into plastic and thermally melt the mixture resulting in a test plastic film. Using the film, we were able to confirm the results reproducibly

that rapid enzymatic degradation (degradation on demand) occurs only when exposed to seawater, both on laboratory test and marine field tests (FY2024 and FY2025). Going forward, our efforts will focus on achieving even faster on-demand degradation through the functional enhancement of plastic-degrading enzymes and the optimization of blending conditions with plastics. In parallel, we will advance the exploration and functional improvement of enzymes capable of degrading multiple types of plastics with different bonding structures. Furthermore, we will continue to promote biomanufacturing approaches for producing monomers for marine-biodegradable plastics from non-edible resources.

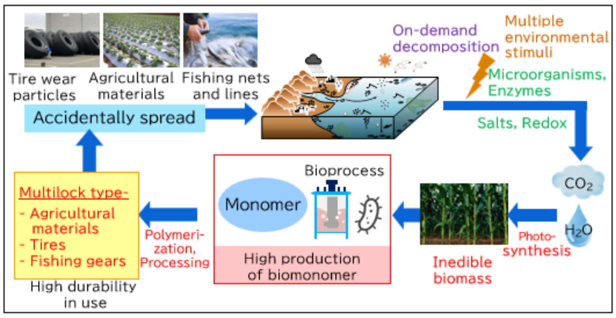

Fig. 11 Development of multi-lock biodegradable plastic and realization of resource recycling

3.5. Research and development of industrial smart cell "Data-driven Integrated BioProduction Management System (Data-driven iBMS)" *2

In the NEDO Project "Development of Production Technology for Bio-based Products to Accelerate the Realization of Carbon Recycling," technology development is being carried out to address challenges associated with practical implementation, with the aim of enabling smart cells optimized at the laboratory scale to demonstrate their capabilities in industrial processes as well. In FY2026, as the final year of the project, it is expected to present concrete examples demonstrating the effectiveness of the developed technologies, as well as a clear pathway toward social implementation. RITE has participated in "Research and Development of Data-driven Integrated Bioproduction Management System," one of the thematic components of this project, since its initial year, and is advancing the development of a set of novel technologies aimed at addressing challenges associated with the practical application of biomanufacturing technologies, specifically issues arising from reduced enzyme activity due to high product concentrations and from heterogeneity within large-scale fermenters (Fig. 12).

Utilizing a technology developed in collaboration with affiliated research institutions that can avoid enzyme activity reduction caused by the product by appropriately substituting the amino acid sequence of the enzyme, in the fiscal year 2025, we actually bred production strains and obtained results in studies using jar fermenters suggesting that this technology contributes to improved productivity. On the other hand, during scale-up, conditions such as temperature, pH, substrates, and dissolved oxygen concentration tend to become locally biased, resulting in heterogeneous environments. In response, we have aimed, in collaboration with partner research institutions, to develop design technologies for robust production strains capable of maintaining high productivity even under such conditions. In FY2025, verification was conducted on proposed genetic modifications expected to confer robustness. These proposals are based on detailed gene expression and metabolite data obtained by RITE under conditions that reproduce localized decreases in dissolved oxygen concentration. Production strains for verification were bred and their productivity was compared using jar fermenters, resulting in the identification of multiple modifications that enable the maintenance of yield even under conditions where dissolved oxygen concentration temporarily decreases. Through the development and validation of technologies that address issues likely to arise in actual production processes, this project aims to contribute to the realization of a carbon-circulating society and a biomanufacturing-based society that supports sustainable economic growth.

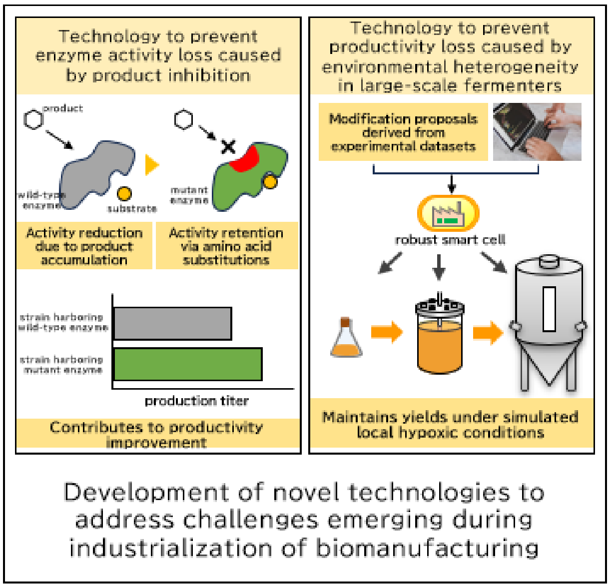

Fig. 12 Development of technologies to address issues that may arise during production

3.6. Biohydrogen "Development of Biofuel Production Technology"

RITE took part in the Japan Science and Technology Agency (JST)-commissioned program on open innovation platforms (COI-NEXT) themed "Carbon Cultivation Hub Challenging the Limits of Carbon Negativity." Started in 2023, we are working on developing biohydrogen production and liquid biofuel production technologies for establishing carbon-cultivation–based fuel-production technology. RITE develops biological conversion technologies for efficient fuel (hydrogen/liquid fuel) production based on various biomass feedstocks. Meanwhile, we collaborate with the participant organizations specialized in biomass cultivation technologies, thus enabling an increase in CO_2 fixation by photosynthesis (Fig. 13). Using these technologies, we target liquid-fuel production for our short- to medium-term goal. Yet since hydrogen is expected to be the ultimate clean energy and is key in realizing carbon neutrality/negativity, our medium- to long-term aim is to develop CO_2-free hydrogen production processes.

One of the key challenges for the social implementation of biomass fuel-production technology is lowering production costs. In addition, the components of biomass feedstock are diverse, and their composition considerably varies depending on the feedstock type. It is challenging to funnel this wide range of demands into a uniform technology. To solve these issues, this project will promote technology development in different fields, including various thermochemical and biological conversion technologies in an integrated manner to enable the construction and expansion of a flexible biomass-based fuel supply system tailored to each regional and feedstock needs.

Based on RITE success in developing a biohydrogen production process with high production rate, we are currently developing producer strain with improved hydrogen yield based on biomass-derived sugars. In order to construct a genetically engineered microorganism with a novel hydrogen production pathway, we examined effects of introduction of the heterologous enzyme complex and optimized its expression level to stably improve the microbial hydrogen-producing ability.

In liquid fuel, previously RITE has also established a bioprocess that efficiently converts C6 and C5 sugars mixture derived from non-edible biomass to ethanol. We improved the RITE bioprocess in this project and revealed that xylose, which is difficult for other organisms to consume, was consumed at a rate equal to or greater than that of glucose, and both sugars were completely consumed. Using this technology, we aim to develop an alcohol-to-jet (ATJ) process to produce a sustainable aviation fuel (SAF) using various biomass feedstocks, such as energy crops, rice with high CO_2 fixation capability, and microalgae with high sugar content.

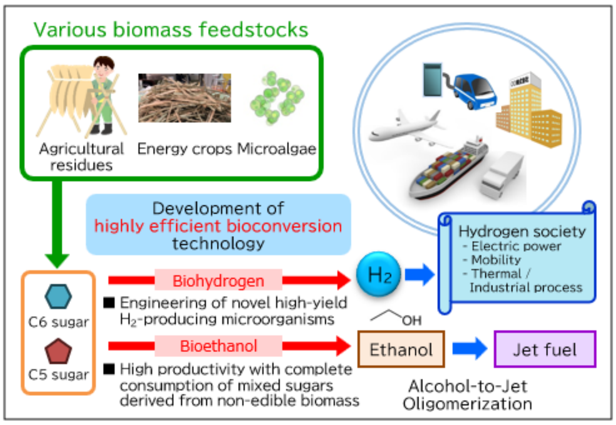

Fig. 13 Development of biohydrogen/bioethanol production technologies

4. Future Industrialization of Our Technologies

4.1. Green Chemicals Co., Ltd. (GCC)

(Head Office・Laboratory: in Kyoto headquarters, RITE; Shizuoka Laboratory: in Shizuoka plant, Sumitomo Bakelite Co., Ltd.) (Here's a link for GCC website)

In February 2010, RITE established the "Green Phenol and High-Performance Phenolic Resin Production Technology Research Association" (GP Association) with Sumitomo Bakelite Co., Ltd. to develop fundamental technologies related to phenol production and phenolic resin production through the application of bioprocesses that use cellulosic raw materials (non-food biomass). The GP Association was reorganized in May 2014 as "Green Phenol Development Co., Ltd." (GPD), which became the first example of demutualization of a technology research association. Green Phenol Development Corporation's trade name was changed to Green Chemicals Co., Ltd. (GCC) in April 2018, in recognition of the fact that GPD technology is able to develop valuable compounds alongside phenol bioproduction. In 2024, GCC's trademarks "Green Chemicals" and "Green Phenol" were registered.

Leveraging the mass production technology and know-how cultivated for green phenol manufacturing, GCC has established mass production technologies for green chemicals such as aromatic compounds, which were previously considered difficult to produce in large quantities. Among them, we possess advanced mass-production technologies for high value-added chemicals such as 4-hydroxybenzoic acid (4-HBA), which is promising for applications like high value-added liquid crystal polymer raw materials, protocatechuic acid, which is promising for use as a raw material in cosmetics and fragrances (vanillin), and shikimic acid, which is a raw material for the anti-influenza drug Tamiflu. For all of these substances, we have obtained confirmation from the Minister of Economy, Trade and Industry (Ministerial Confirmation) for the second-class use of genetically modified organisms as production strains in industrial applications, and we are promoting the commercialization of green compounds and business development activities (Fig. 14).

At present, we are receiving inquiries from a considerable number of companies both domestically and internationally. In order to respond appropriately to these diverse needs, we intend to promote the social implementation of biomanufacturing by addressing various challenges, including the further reduction of production costs and the enhancement of product quality.

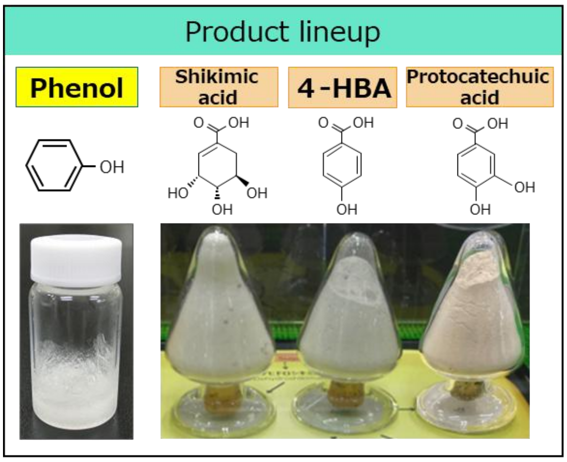

Fig. 14 Major product lineup of Green Chemicals Co., Ltd.

4.2. Green Earth Institute Co., Ltd. (GEI)

(Head office: 6F Q Plaza Shinjuku 3-chome, 3-5-6 Shinjuku, Shinjuku-ku, Tokyo, Laboratory: 2-5-9 Kazusa-kamatari, Kisarazu-shi, Chiba)

(Click here for the Green Earth Institute Inc. website)

In September 2011, RITE established Green Earth Institute Co., Ltd. (GEI), as a venture company originating from RITE in order to commercialize “RITE Bioprocess.” *1 Due to successful business results, the company was listed on the Tokyo Stock Exchange (Mothers) in December 2021. By the following April, it moved to the Tokyo Growth Market due to market reorganization.

GEI is promoting research and development as well as commercialization with domestic and international partner companies through the Biofoundry project commissioned by NEDO, the Green Innovation Fund project, and the Biomanufacturing Revolution Promotion project, and is attempting to develop a “Vertically Integrated Biofoundry.”

In addition, GEI established a joint venture, "Morizora Biorefinery LLC," in July 2025 to manufacture and sell bioethanol and other products using woody biomass as a raw material, and is working on the realization of sustainable aviation fuel (SAF).

4.3. Joint Research with Companies

Besides the main compound products introduced in this overview (Section 2.3), biomanufacturing is possible for numerous other substances, and RITE is developing collaborative research tailored to the needs of each individual companies. Since the Japanese government declared its goal of “carbon neutrality by 2050” in October 2020, inquiries and requests from companies aiming to expand their products overseas have surged, and the number of joint research projects has also increased. The requests vary, ranging from the desire to quickly convert fossil resource-derived products to bio-based production, to the goal of transitioning main products and key raw materials from fossil resources to bio-based sources over the mid- to long term, to manufacture high-value-added bio-products using waste generated from own production as raw materials. Leveraging its advanced expertise and extensive experience, RITE offers biomanufacturing solutions that are closely tailored to the specific needs of each company.

5. Closing remarks

RITE will continue to advance biomanufacturing technologies, including smart cell creation technology, by leveraging the national projects introduced in Chapter 3. At RITE Biomanufacturing Center, completed in November 2025 (Fig.15), it will be possible to provide services for the development of optimal biomanufacturing technologies for each product. This will be achieved by leveraging RITE's accumulated technological capabilities, including "RITE Bioprocess" and "Smart Cell Creation Technology," along with extensive knowledge and technologies for utilizing underused domestic resources as raw materials, highly advanced research facilities, and development technologies for production processes that require a certain scale, which are difficult for individual companies to implement due to considerations such as cost performance and maintaining competitiveness.

RITE will continue to undertake the development of microbial production strains required by numerous companies that wish to enter the biomanufacturing industry but hesitate to do so, and provide production technologies. By consolidating RITE's expertise in biotechnology, research facilities, technologies, and information into a "Microbial Development Platform," we aim to contribute to the promotion of Japan's smart cell industry and to the near future establishment of biomanufacturing in society, particularly in the energy and chemical industry sectors.

Compounds that were previously difficult to produce with microorganisms may now achieve high production with RITE's latest technologies. If you have compounds you would like to make with bioconversion, or if you consider the companies considering the high-value-added bio-development of waste resources, or if you are attracted to RITE's biomanufacturing, please contact us. We look forward to collaborating with you to drive innovation and sustainability in the biomanufacturing industry.

For more details about the "RITE Bio Manufacturing Center," please also refer to the topics article in this "RITE today."

[*1] "RITE Bioprocess" is a registered trademark of RITE.

[*2] This article is based on results obtained from a project commissioned or subsidized by NEDO (New Energy and Industrial Technology Development Organization).

Fig. 15 "RITE Biomanufacturing Center"