



IN A NUTSHELL

With its 15th Five-Year Plan, China aims to advance non-fossil energy, large-scale biomanufacturing, digital process control and biotechnology-assisted agricultural breeding.

Renewable electricity and green hydrogen shall foster green chemical production as shown by methanol, ammonia and sustainable aviation fuel projects.

China already has a large fermentation industry for ethanol, amino and organic acids, vitamins, enzymes and polymers, and aims to expand it to carbon-efficient feedstocks and new platform chemicals.

Basic strain improvement, AI- and digitally supported biomanufacturing advance synthetic biology—backed by major research infrastructures such as large-scale biofoundries.

Institute of Synthetic Biology (iSynBio), Shenzhen Institutes of Advanced Technology, Chinese Academy of Sciences. The two upper cantilevered floors house nine automated, robot-supported biofoundries for biomanufacturing through DNA construction, cultivation, analytical testing and data evaluation. The stone in front of the building commemorates animals used in experimental scientific research. Such memorials are found at a number of Chinese universities and biomedical research institutions. They reflect the growing emphasis on research ethics, animal welfare and respect for life in the Chinese life sciences. Photo: R. D. Schmid (2024)

China

From Green Energy to Smart Cells

This March, China's National People's Congress adopted the 15th Five-Year Plan that retains the long-standing objective of modernising industry but gives greater weight to green production and lifestyles.

Theme	Key objective (2026–2030)
Green transition	Establish a green production model and reach the national carbon peak target
Industrial biotechnology	Scale up biomanufacturing, enzyme engineering, AI-assisted biological design and intelligent fermentation
Digitalisation	Increase the digital economy share of GDP from 10.5% to 12.5%.
Agriculture	Expand biotechnology-assisted crop breeding and highly mechanised agriculture
Energy	Increase the share of non-fossil energy from 21.7% to 25%
Environment	Advance the Beautiful China programme through cleaner air, water and ecosystems

Selected objectives of China's 15th Five-Year Plan that are relevant to the bio-based industries.

GDP: Gross Domestic Product

During China's 14th Five-Year Plan (2021–2025), research and development expenditure rose from 2.439 trillion Chinese Yuan (CNY, ca. 0.31 trillion Euros) in 2021 (2.4% of GDP) to 3.926 trillion CNY (ca. 0.50 trillion Euros) in 2025 (2.8% of GDP), R&D personnel increased from 5.24 to 7.57 million. In 2025, 6.32 million valid invention patents were in force—more than twice the 3.06 million recorded in 2020. The 15th Five-Year Plan (2026–2030) is set to continue this trend.¹⁾

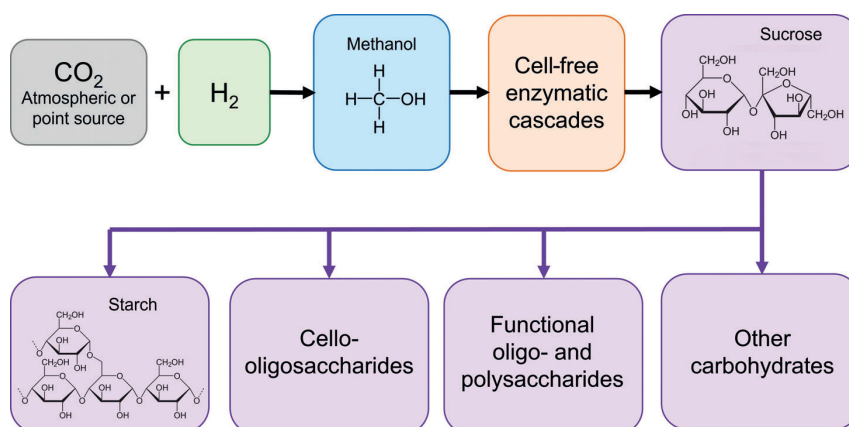
The relevant elements for the chemical and bio-based industries are: expansion of non-fossil energy, large-scale biomanufacturing, digital process control, biotechnology-assisted agricultural breeding and continuation of the Beautiful China programme (table). The Beautiful China initiative is China's national framework for improving environmental quality through green and low-carbon development, pollution control and ecosystem restoration within the broader concept of ecological civilisation.²⁾

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Biotechnology

China has already expanded its capacity in biotechnology during the 14th Five-Year Plan, e.g. in improving the digital infrastructure to change experimental practice: automated DNA assembly, high-throughput cultivation, online process analytics, model-based fermentation control and machine-learning-assisted enzyme or strain design. One example is the speed breeding of tomatoes by genome editing with artificial-intelligence-based robots (GEAIR).³⁾

Other examples from the Tianjin Institute of Industrial Biotechnology: The design tool ET-OptME combines enzyme-resource and thermodynamic constraints when selecting metabolic-engineering targets, thereby excluding interventions that are stoichiometrically possible but physiologically implausible. The synthetic biology tool SynBioGPT uses a large-language model to integrate strain-engineering knowledge and propose experimental strategies. For both tools, published data do not yet demonstrate improved industrial titre or productivity.^{4,5)} The Tianjin Institute claims a complete set of microbial host organisms for biomanufacturing and reports nearly 2,000 invention patents and research agreements with more than 300 enterprises to bring bio- or biomanufactured products to market.



C1-to-carbohydrate platform for producing sugars and oligosaccharides from CO₂. Cell-free multi-enzymatic cascades convert methanol to saccharides. In 2025, the overall conversion of CO₂ to sucrose was 86% with a production rate of 5.7 g·L⁻¹·h⁻¹, and scientists extended the platform to starch and cellooligosaccharides. Data from Lit. 11,12)

Green energy, green chemicals

In 2025, non-fossil sources generated about 42 % of China's electricity. Fossil energy nevertheless remained dominant in many energy-intensive processes, and China still accounted for roughly 30 % of global greenhouse-gas emissions. The relevant change is not the replacement of fossil energy, but the addition of renewable electricity, green hydrogen produced via electrolysis without direct CO₂ emissions and carbon-management infrastructure: China operates the world's largest national carbon market. Although its effect on individual chemical and biotechnological processes requires case-specific assessment, it supports the trend towards green production.

If the cost is competitive, green hydrogen may link renewable electricity to chemistry, e.g. to replace fossil-derived hydrogen in ammonia and methanol synthesis and supply reducing power for processes that combine catalytic and biological conversion. A national demonstration programme aims to reduce the average end-user price below 25 CNY·kg⁻¹ (ca. 3.21 Euros) by 2030.

Construction began in Shenyang in April 2026 on a project intended to produce 100,000 t of green methanol, 300,000 t of sustainable aviation fuel and 100,000 t of green ammonia using renewable hydrogen and biomass gasification. At the Shanghai Chemical Industry Park, a plant commissioned in December 2025 produces 100,000 t of green methanol per year. The plant converts biogas from organic waste to methanol using wind-derived electricity; its operators report an approximately 80 % lower carbon footprint than for conventional fossil methanol.

Fermentation

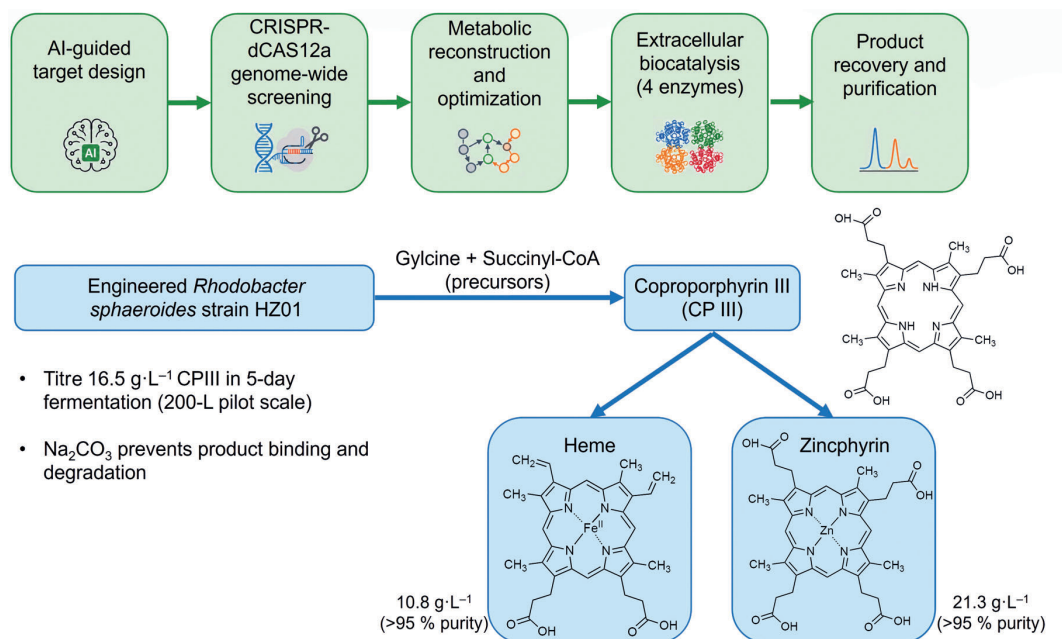
China already has a large fermentation industry for ethanol, amino and organic acids, vitamins, enzymes and polymers—with companies such as Fufeng, Meihua and Eppen that are among the leading Chinese producers of bulk amino acids and the major citric acid producers Ensign World and Cofco. The 15th Five-Year Plan is set to extend China's competence to carbon-efficient feedstocks and new platform chemicals.

A nationwide programme to promote E10 ethanol gasoline was announced in September 2017, with the objective of achieving essentially nationwide coverage by 2020.⁶⁾ However, the programme was not fully implemented, partly because of food security concerns about grain-based production. The average ethanol content in gasoline was estimated at about 2.1 % in 2025.

Gas fermentation offers another carbon source: the steel producer Shougang Jingtang operates a plant with an annual ethanol capacity of about 46,000 t from steel mill off-gases.

Current green-fuel projects follow different routes. The Shenyang project, construction of which began in April 2026, combines biomass gasification with renewable hydrogen and downstream fuel synthesis. The Shanghai Chemical Industry Park plant, commissioned in December 2025, starts from biogas derived from organic waste and uses wind-derived electricity. Both routes therefore differ from direct CO₂ hydrogenation.^{7,8)}

Established fermentation capacities also support other materials, such as polymers. The company Cathay Biotech reports annual capacities of 75,000 t of fermentation-derived long-chain dicarboxylic acids, 50,000 t of bio-based pentamethylenediamine and



a) Artificial intelligence(AI)-assisted smart cell engineering, e.g. to produce porphyrins. b) Genome design and extracellular catalysis enable high-level production of heme and zinc porphyrins. Data from Lit. 14)

100,000 t of bio-based polyamides per year at its Jinxiang and Wusu sites.⁹⁾ The biotech company Bluepha operates a plant in Yancheng that produces 5,000 t of polyhydroxyalkanoates (PHA) annually – a biodegradable polyester produced by microorganisms. Yancheng has published plans to increase capacity to 25,000 t.¹⁰⁾

Industrial enzymes form another established sector, with applications in food processing, brewing and animal feed. Among international enzyme manufacturers that helped develop the Chinese enzyme market decades ago, Denmark's Novonesis retains a major foothold with research, production, sales and marketing activities in six Chinese cities and more than 1,000 employees. Chinese producers such as Xike, Sunson and Vland are important domestic competitors. A scientifically distinct approach at the Tianjin Institute of Industrial Biotechnology uses enzymes outside living cells. The original 2021 system converted CO₂ to starch via methanol. In 2025, the group reported a broader cell-free platform for synthesis of sucrose from C₁ and C₃ molecules: protein engineering improved key enzyme efficiencies by factors of 3–71 compared with the original system described in 2021 (figure on the left). The platform was extended to primer-free starch and long-chain cellooligosaccharides.^{11–13)}

This work does not yet establish an energetically competitive route to starch, but it illustrates why food security remains a strategic issue in China. Historical experience of recurrent food shortages, com-

bined with the continuing challenge of feeding a large population with limited arable land, gives technologies that decouple food production from conventional agriculture significance beyond their immediate economics.

Synthetic biology

Synthetic biology extends strain improvement beyond mutation and selection to the planned construction of metabolic functions. Genome editing, pathway design, enzyme engineering and computational modelling are combined to obtain defined products and to identify bottlenecks that can be corrected experimentally. The products accessible to synthetic biology span a wide range of molecular complexity. Engineered microorganisms or plants can produce comparatively simple platform chemicals such as lactic or *trans*-aconitic acid at titres approaching industrial relevance. The same engineering principles can also provide access to structurally complex molecules whose conventional chemical synthesis is considerably more demanding.

An example of rationally designed biomanufacturing is porphyrin production using the bacterium *Rhodobacter sphaeroides* combining cell-factory engineering and a separate enzymatic conversion step: By regulating the activity of specific genes and controlling phosphorylation, coproporphyrin III (CP III) was produced at 200 L pilot scale by batch ferment-

tation with >95% purity. Engineered metal chelates and coproheme decarboxylase then converted CPIX extracellularly to heme and zincphyrin (figure p. 57).¹⁴⁾ Porphyrins are not merely biochemical model products. Their extended π -electron systems and tunable metal centres make the porphyrin family attractive for high-technology applications such as dye-sensitised and perovskite photovoltaics, molecular spin qubits and quantum information technologies.¹⁵⁾

China has built a research infrastructure for systematic strain construction. One example is the Institute of Synthetic Biology (iSynBio) at the Shenzhen Institutes of Advanced Technology. It houses more than 60 principal investigators and nine biofoundries. In biofoundries, DNA construction, cultivation, analytical testing and data evaluation are organised as a design-build-test-learn cycle; robotics permit many variants to be examined in parallel. Se-

lected Chinese biomanufacturing examples and international peers are summarised in the table below.

Sustainable aviation fuel

Sustainable aviation fuel (SAF) links renewable carbon, green hydrogen and catalytic conversion. In June 2024, a C919 and an ARJ21 aircraft completed demonstration flights using SAF produced by Sinopec from waste cooking oil. China’s first national SAF application pilot began in September 2024 with twelve flights by Air China, China Eastern and China Southern from four airports. Hydroprocessed waste oils represent one route; biomass/syngas conversion, as planned for the 300,000 t per year Shenyang second phase, represents another. Depending on feedstock and process, SAF can substantially reduce life-cycle greenhouse-gas emissions relative to fossil jet fuel.^{8,16,17)}

Application area	Chinese example	Status (2026)	International peers
Automated biofoundry	Shenzhen biofoundries (Institute of Synthetic Biology (iSynBio) at Shenzhen Institutes of Advanced Technology)	National and local research infrastructure; AI-supported design-build-test-learn platform	Ginkgo Bioworks (USA); Edinburgh Genome Foundry (UK)
Platform chemicals	Qingdao Institute of Bioenergy and Bioprocess Technology (QIBEBT), Chinese Academy of Sciences (CAS): <i>trans</i> -aconitic acid	Pilot-scale biomanufacturing of a novel bio-based platform chemical	Genomatica (USA)
Bio-based polymers	Cathay Biotech: long-chain dicarboxylic acids; pentamethylenediamine	75,000 t·a ⁻¹ long-chain dicarboxylic acids; 50,000 t·a ⁻¹ pentamethylenediamine; 100,000 t·a ⁻¹ bio-based polyamides	Genomatica (USA); Evonik (Germany)
Biodegradable plastics	Bluepha: polyhydroxyalkanoate (PHA) biopolymers	Commercial production; Yancheng capacity currently 5,000 t·a ⁻¹ ; expansion to 25,000 t·a ⁻¹ planned	Danimer Scientific (USA); RWDC Industries (Singapore)
Nutritional ingredients	Cabio Biotech: human milk oligosaccharides (HMOs), arachidonic acid (ARA), docosahexaenoic acid (DHA)	Commercial microbial production for infant nutrition	dsm-firmenich (Switzerland); Novonesis (Denmark)
Biomanufactured biomaterials	Bloomage Biotech: hyaluronic acid	Large-scale microbial production	Contipro (Czech Republic); Kewpie (Japan)
Bioplastics	Henan Jindan: L-lactic acid / polylactic acid (PLA)	Large-scale industrial fermentation	NatureWorks (USA); TotalEnergies Corbion (Netherlands)
Plant molecular farming	Oryzogen (Wuhan): recombinant human serum albumin in rice	Commercial production of plant-derived biopharmaceuticals	Ventria Bioscience (USA)

[†]International peers are indicative comparators and do not imply technological equivalence.

Examples of industrial biomanufacturing in China and international peers. International peers are indicative comparators and do not imply technological equivalence.

Feed biotechnology

Feed production is a major use of agricultural biomass and therefore competes indirectly with food production for land, crops and other resources. Conventional microbial protein production often starts from sugars or starch hydrolysates. Replacing these feedstocks by C₁ substrates could reduce this competition and China's dependence on imported protein feeds. Methanol-based single-cell protein is a route to produce microbial biomass rich in protein without arable land and independently of soybean cultivation.

Chinese researchers have developed the methylotrophic yeast *Komagataella phaffii* (formerly *Pichia pastoris*) as a methanol-to-single-cell-protein platform. A 10,000-t-scale industrial demonstration has already been reported, and a 100,000-t-scale single-cell protein project has subsequently been announced. Methanol itself is not necessarily renewable: in China it can be produced from coal, but it can also be derived from biomass, biogas or CO₂ combined with low-carbon hydrogen. The environmental value of the protein route therefore depends strongly on the origin of the methanol.¹⁸⁾

A complementary C₁ gas-protein route uses industrial one-carbon gases rather than methanol alone.¹⁹⁾ Researchers have reviewed microbial protein production from methane, carbon monoxide and carbon dioxide as potential substitutes for fishmeal or soybean meal in aquaculture. Such gas-fermentation processes could produce feed protein with little demand for arable land, although their industrial economics remain process- and site-dependent.

Environment

The Beautiful China programme provides the environmental context for the bioeconomy, although improvements in air, water or biodiversity cannot be attributed to biotech alone. In 2025, the average concentration of fine inhalable particles with diameters of 2.5 micrometers or smaller in the air across China's 339 prefecture-level and higher cities was 28.0 µg·m⁻³, and 89.3% of days met the national good-air-quality categories after adjustment for exceptional dust events.²⁰⁾ Surface-water quality also improved: 91.4% of the national monitoring sections reached classes I–III, i.e. the three best categories of China's five-class surface-water quality system.

Biotechnology contributes directly through wastewater treatment: in 2023, China was estimated to operate more than 5,000 biological sewage-treatment plants, including roughly 3,000 urban activated-sludge installations.

Ecosystem recovery depends mainly on regulation and land management. During the 14th Five-Year Plan, approximately 12.3 million hectares of forest were added, while the first five national parks covered about 230,000 km². The Yangtze river provides a measurable example: a ten-year commercial-fishing ban began in 2021; the 2025 survey counted 1,426 Yangtze finless porpoises, 177 more than in 2022, and monitoring between 2021 and 2025 recorded 351 fish species, 43 more than before the ban. In an unusual historical-ecological approach, researchers used references to finless porpoises in 724 Chinese poems spanning some 1,400 years as historical evidence to reconstruct changes in the species' geographical distribution.^{21,22)}

China's transition towards a bioeconomy is still work in progress. Nevertheless, combining large-scale industrial biotech, synthetic biology, AI-supported biofoundries and environmental programmes has created one of the world's most dynamic innovation environments for sustainable chemistry. ■

The authors used ChatGPT as assistance in preparing tables and figures.

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