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Editorial Note

Engineering Life: Biotechnology and Synthetic Biology as the Next Industrial Frontier

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A shift is underway in how materials, medicines, fuels, and food are produced. Industrial systems centered on extraction, transformation, and combustion have supported modern development, while also being associated with environmental impacts such as emissions and waste. An alternative approach, often described as engineered biology, emphasizes cultivation, fermentation, and synthesis and is viewed as a potential direction, though its impacts remain under evaluation. Synthetic biology, which applies engineering principles to the design and construction of living systems, is increasingly being developed beyond academic laboratories. It is becoming an industrial platform (Cameron et al., 2014; Mao et al., 2021). The global synthetic biology market was valued at approximately USD 19.75 billion in 2025 and is projected to reach USD 56.48 billion by 2031, at a compound annual growth rate of 19.14% (Mordor Intelligence, 2026; Zhang et al., 2025). This trajectory reflects the convergence of several enabling forces: dramatic reductions in the cost of DNA synthesis and sequencing, the proliferation of CRISPR-based genome editing, the rise of AI-guided protein and metabolic pathway design, and the maturation of automated biofoundry infrastructure that can compress the design-build-test-learn cycle from years to weeks.

The Architecture of Engineered Biology

At its core, synthetic biology treats the genetic code of an organism as programmable software and the organism itself as a production platform. Similar to how an electrical engineer selects components and designs circuits to achieve a specific function, a synthetic biologist combines genetic elements such as promoters, coding sequences, and regulatory components within a chosen host to produce a desired output, such as a molecule, material, or signal (Jinek et al., 2012). The CRISPR-Cas9 system and its derivatives have made precision genome editing tractable at scale (Doudna and Charpentier, 2014). Beyond gene editing, synthetic biology also draws on metabolic engineering, which involves redirecting an organism's metabolic pathways to increase production of a target compound (Nadhif et al., 2017). It also uses cell free systems that operate cellular machinery outside living cells, allowing greater control and fewer constraints from cellular processes (Rahyussalim et al., 2017; Whulanza et al., 2014).

AI-guided protein design tools, including AlphaFold and related approaches, have reduced tasks that previously required years of crystallographic research to hours of computation, contributing to a shift toward more data-driven methods in synthetic biology (Jumper et al., 2021; Nature Methods, 2022). The integration of machine learning into metabolic pathway optimization, gene circuit design, and strain engineering is contributing to a shift toward a more computational approach in synthetic biology. This development shows similarities to the materials informatics approach discussed in a previous IJTech editorial (January 2024).

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Central to this transformation is the biofoundry, a highly automated facility in which the design, build, test, and learn cycle is carried out at high throughput. Equipped with robotic liquid-handling systems, automated DNA assembly platforms, and integrated computational pipelines, a biofoundry can execute hundreds of design iterations in parallel (Holowko et al., 2021). Governments that view biomanufacturing as part of strategic infrastructure, including the United Kingdom, Singapore, Denmark, and the United States, have made significant investments in national biofoundry capacity (Hillson et al., 2019). In the Asia-Pacific region, the Bioinnovation APAC 2026 forum convened in Singapore in March 2026, gathering over 250 participants to accelerate industrial biomanufacturing collaboration, signalling that Southeast Asia is positioning itself as an active participant rather than a passive recipient in this buildout (Biospectrum Asia 2026).

1. Industrial Applications and Regional Opportunity

The applications of synthetic biology to industrial production are diverse and, in many cases, near-term. Precision fermentation is enabling the production of proteins, specialty chemicals, flavors, and functional ingredients that were previously extracted at high ecological cost or synthesized using toxic reagents (Paddon et al., 2013; Ro et al., 2006). Engineered organisms are being developed to produce next-generation biofuels, such as hydrogen and fatty acid–derived compounds, as alternatives to earlier biofuels linked to competition with food production for land and water.

In Southeast Asia, Indonesia and Malaysia produce oil palm biomass at a large scale, which is widely regarded as a waste management challenge and may also serve as a potential carbon feedstock for domestic biomanufacturing. As noted in the our editorial on March 2024, oil palm biomass has already demonstrated potential as a precursor for graphene-family advanced materials; synthetic biology offers a complementary route to valorize the same resource through microbial conversion into biodegradable polymers, platform chemicals, and bio-based coatings (Ijtech march 2024, Kusrini et al., 2019).

In South America, Brazil offers perhaps the world's most mature proof of concept for biology-based industrial transformation. Its flex-fuel vehicle fleet, in which bioethanol derived from sugarcane fuels over 80% of light vehicles, reflects the long-term deployment of fermentation engineering at national scale (Bonini et al., 2025). The next frontier includes second-generation cellulosic ethanol, which uses sugarcane bagasse and other residues instead of sugar, along with expanding biorefineries toward higher-value biochemicals, bioplastics, and biosurfactants.

In Africa, Nigeria presents a comparable case due to its position as the world's largest producer of cassava. The crop generates an estimated 40 million tonnes of processing waste annually across Sub-Saharan Africa, over half of which is currently landfilled or incinerated (Hierro-Iglesias et al., 2022). Engineered microorganisms that convert cassava starch and lignocellulosic residues into polyhydroxyalkanoates, which are biodegradable plastics with properties comparable to petroleum-derived polypropylene, may provide a way to utilize this waste stream as a higher-value product.

2. Challenges and the Engineering Research Agenda

The transition from laboratory demonstration to industrial deployment is not straightforward. A key challenge is the gap between laboratory and commercial scale, where factors such as metabolic burden, contamination control, process consistency, and genetic stability become limiting (Asin-Garcia and Martins dos Santos, 2025). These challenges can be framed as engineering problems, shaping a research agenda in which chemical engineers, process engineers, and bioprocess specialists have important roles to play (Tellechea-Luzardo et al., 2022). The development of digital twins for bioprocess systems, which integrate computational biology models with real-time sensor data and process control, reflects a convergence of themes previously explored in our editorials on digital twins (Ijtech March 2024) and AI in engineering (Ijtech November

2025). Regulatory frameworks for engineered organisms vary considerably across jurisdictions, and biosafety assessment processes differ in scope between countries (OECD 2025). The ethical dimensions of synthetic biology include ecological risks associated with the release of engineered organisms, the dual use potential of genome editing tools, and the distribution of benefits (Lee et al., 2025). These issues warrant careful consideration by the engineering community.

3. This issue

The convergence of biology and engineering is shaping current industrial innovation, with engineering methods contributing to this transition. IJTech invites research on areas such as bioprocess scale up, biomaterials manufacturing, biosensors, biofoundry systems, and the integration of computational and biological processes. This field brings together engineering expertise, regional resources, and sustainability considerations, offering scope for further contributions.

The first study, written by Tien and Tuan, 2026, assesses the influence of thermal and mechanical loads on a diesel-engine piston after conversion to compressed natural gas operation. This study numerically evaluates piston stress and deformation under diesel, thermal, and combined loading conditions. It shows that CNG reduces mechanical loading but increases thermal effects, making thermal stress the dominant durability concern in converted engines (Tien and Tuan, 2026).

The second study, written by Rompas et al., 2026, validates a shell-and-spiral coil fuel preheating system that uses diesel exhaust heat to reduce CO emissions from B30-fueled engines. This study combines CFD simulation and no-load engine experiments to assess fuel temperature rise and resulting emission changes at different engine speeds. It shows that moderate preheating significantly lowers CO emissions at low-to-medium speeds, supporting passive waste-heat recovery for cleaner biodiesel engine operation (Rompas et al., 2026).

The third study, written by Ajouz et al., 2026, examines how leadership style drives FinTech orientation in financial institutions through the mediating roles of strategic agility and innovation. This study applies CB-SEM to survey data from Palestinian financial institutions and tests the indirect pathways linking leadership to digital readiness. It shows that leadership significantly strengthens FinTech orientation, with strategic agility emerging as the strongest capability-based mediator in constrained environments (Ajouz et al., 2026).

The fourth study, written by Beketov et al., 2026, proposes a multi-objective optimization approach for labor allocation in surface field development projects. This study applies Pareto optimization and Monte Carlo-based uncertainty analysis to balance project duration and labor costs across alternative staffing scenarios. It identifies 21 Pareto-optimal scenarios, including 17 that satisfy contractual deadlines, offering a flexible decision-support tool for managing large oil and gas construction projects (Beketov et al., 2026).

The fifth study, written by Syahrullah et al., 2026, develops a Fuzzy Delphi model to identify and prioritize uncaptured value in circular manufacturing within the heavy equipment industry. This study reviews 35 uncaptured values and uses expert consensus to retain and rank the most relevant operational bottlenecks. It highlights weak recovery quality control, limited viable end-of-life product supply, and unfavorable recovery characteristics as the main constraints on circular value capture (Syahrullah et al., 2026).

The sixth study, The next study, written by Marimin et al., 2026, develops a strategy to improve sugarcane agroindustry supply chain sustainability through empirical assessment of economic, social, environmental, and resource dimensions. This study applies FIS, MDS, and ANFIS using 29 indicators across two Indonesian sugar agroindustries. It highlights priority indicators and action plans tailored to each case, offering practical lessons for strengthening long-term supply chain sustainability performance (Marimin et al., 2026).

The seventh study, written by Ho et al., 2026, examines technology acceptance in rail-based public transportation through an integrated model linking Big Five personality traits, intention to use, social support, and user experience. This study applies SEM to survey data from 584 Jakarta-area commuters to explain continuance-oriented acceptance of MRT, LRT, and KRL systems. It shows that personality traits shape acceptance through distinct motivational, social, and experiential pathways (Ho et al., 2026).

The eight study, written by Purnomo et al., 2026, develops triangular microstrip array antennas for circularly polarized synthetic aperture radar applications on UAVs and low-Earth-orbit microsatellites. This study designs and evaluates sixteen-patch and eight-patch array configurations using corporate-fed architectures to achieve compact, lightweight, and efficient CP-SAR performance. It shows promising gain, axial ratio, beamwidth, and efficiency, confirming triangular microstrip arrays as feasible radiating elements for low-cost remote sensing platforms.

The ninth study, written by Farouk et al., 2026, proposes hybrid reinforcement-learning schedulers for 5G burst traffic under heterogeneous QoS demands. This study develops and compares A3C-PPO, A3C-PPO-Persistent, and A3C-TD3 against conventional and standard RL schedulers in a realistic multicell environment with ULL, VoIP, V2X, and video traffic. It shows that A3C-PPO delivers the most balanced performance, reducing jitter and substantially improving packet delivery under heavy network loads).

The tenth study, written by Rante et al., 2026, presents an XR-based immersive room for climate change storytelling that integrates three-wall projection mapping, gesture and voice interaction, and multisensory physical feedback. This study evaluates technical performance using latency, gesture-recognition, and voice-recognition tests under varying conditions. It shows low perceived latency and stable multimodal interaction, providing a technical basis for future XR climate communication systems (Rante et al., 2026).

The eleventh study, written by Fernandez et al., 2026, proposes an NSGA-II-optimized neuro-fuzzy controller for robust stabilization of the nonlinear Van de Vusse reactor. This study co-optimizes ANFIS membership functions and consequent parameters to balance tracking accuracy and control effort under inverse-response dynamics and parametric uncertainty. It shows major performance gains over classical PID and baseline ANFIS controllers, supporting interpretable multi-objective control for complex chemical processes (Fernandez et al., 2026).

The next study, written by Duan et al., 2026, presents an energy-efficient TinyML fall detection system for wearable edge devices using a CNN-LSTM model. This study combines tri-axial accelerometer signals with real-time microcontroller deployment to achieve robust cross-dataset performance and low-power inference. It reports high accuracy on KFall and SisFall and successful ESP32-S3 implementation, supporting practical long-duration elderly monitoring on resource-constrained devices).

The thirteenth study, written by Glukhov et al., 2026, introduces the AI Regional Asymmetry (AIRA) methodology to assess and mitigate global disparities in artificial intelligence development. This study builds a composite asymmetry index across 23 indicators spanning computational capacity, talent, data concentration, and capital flows, then applies inequality metrics and alliance-based scenario modeling. It highlights international cooperation as a practical strategy for reducing AI inequality and fostering more inclusive AI-driven growth (Glukhov et al., 2026).

The fourteenth study, written by Maaz et al., 2026, proposes an Explainable Artificial Intelligence (XAI) model for transparent and trustworthy construction tender evaluation. This study integrates data preprocessing, predictive modeling, and SHAP-based explainability to generate global and contractor-level insights for ranking and audit support. It shows that XAI can improve transparency and justification in tender deliberation while preserving professional judgment in final award decisions (Maaz et al., 2026).

The fifteenth study, written by Gutman et al., 2026, develops a fuzzy multi-criteria approach to assess regional biochar market potential in Russia. This study ranks 78 regions using six proxy indicators related to fertilizer use, irrigation, degraded land, livestock, and agricultural output, with clustering used to validate regional groupings. It identifies territories as the strongest markets for targeted biochar development (Gutman et al., 2026).

The sixteenth study, written by Liandana et al., 2026, proposes a semi-adaptive sliding window method to improve sensor-based human activity recognition using triplet subwindow similarity and growth capping. This study evaluates the method with XGBoost and LightGBM on four benchmark accelerometer datasets. It shows consistently high recognition accuracy, demonstrating that adaptive segmentation can improve HAR performance across diverse activity datasets (Liandana et al., 2026).

The seventeenth study, written by Nguyen et al., 2026, develops an embedded AI trap that detects oriental fruit flies from wingbeat sounds using an acoustic sensor and CNN model. This study processes orchard audio into spectrograms and deploys the classifier on an ESP32 microcontroller for real-time field use. It achieves up to 96.86% accuracy, supporting low-power, compact pest monitoring in agriculture (Nguyen et al., 2026).

The eighteenth study, written by Le and Loan, 2026, investigates $SrLaAlO_4$:Yb/Er@SiO_2 as a strong green-emission phosphor for solid-state white LEDs. This study optimizes Yb^{3+} concentration and SiO_2 addition to enhance upconversion emission, lumen output, and color uniformity. It shows that 4 mol% Yb^{3+} gives the strongest green emission, while SiO_2 incorporation improves white-LED optical performance and reduces color deviation (Le and Loan, 2026).

The next study, written by Madsuha et al., 2026, investigates graphene oxide synthesized from recycled dry-cell battery waste as a friction modifier in polyalphaolefin lubricants. This study evaluates GO additions of 1, 3, and 5 wt% to examine friction reduction, wear resistance, and lubricant film stability. It identifies 1 wt% GO as the optimum formulation, achieving major friction and wear reduction while demonstrating a sustainable upcycling route for battery waste (Madsuha et al., 2026).

The twentieth study, written by Adlim et al., 2026, develops biodegradable composite films reinforced with copper nanoparticle-coated abaca fibers for antibacterial and mechanical enhancement. This study synthesizes CuNP-coated fibers, incorporates them into PVA–starch–glycerol–chitosan films, and evaluates conductivity, tensile properties, water absorption, and antibacterial activity. It shows that stepwise-coated CuNP fibers improve film strength and elongation while providing localized antibacterial performance comparable to gentamicin (Adlim et al., 2026).

The twenty-first study, written by Muhammad et al., 2026, investigates green synthesis of TiO_2 nanoparticles using Melastoma malabathricum fruit extract and lime juice for dye-sensitized solar cell photoanodes. This study applies a sol-gel route and evaluates crystallinity, particle size, bandgap, morphology, and photovoltaic behavior of the resulting TiO_2. It shows that plant-mediated TiO_2 improves photoanode performance, with the fruit-extract sample achieving the highest DSSC efficiency of 3.12% (Muhammad et al., 2026).

The twenty-second study, written by Cahyadi et al., 2026, develops a freeze-dried biphasic bone scaffold based on hydroxyapatite–β-tricalcium phosphate reinforced with polycaprolactone, copper, and zinc for alveolar bone regeneration. This study evaluates its physicochemical structure, porosity, absorption behavior, and compressive properties against a xenograft control. It shows markedly higher compressive and yield strength, highlighting its potential for load-bearing bone regeneration applications (Cahyadi et al., 2026).

The twenty-third, written by Agureev et al., 2026, investigates single- and multilayer NiAl-based composites produced by spark plasma sintering for improved corrosion resistance. This study examines their phase structure and electrochemical behavior using alloying additives such as Cr, Co, Ti, Mo, V, Re, and Zr in saline solution. It shows that multilayer NiAl-based composites achieve the most favorable passive-state corrosion characteristics and remain stable after six months of testing (Agureev et al., 2026).

The twenty-fourth, written by Alam et al., 2026, develops and validates a VOF-based CFD model for CO_2–water slug flow formation in a circular T-junction microchannel reactor. This study performs mesh sensitivity analysis and validates bubble-length predictions against experiments under multiple flow-rate conditions. It shows strong agreement with experimental results, with deviations of only 3.04%–6.90%, supporting reliable hydrodynamic modeling for future CO_2 microchannel reactor optimization (Alam et al., 2026).

The next study, written by Dwiyati et al., 2026, compares acoustic emission signatures of magnesium and SK-5 steel during microblanking using wavelet scattering transform and FFT analysis. This study evaluates how these signal-processing methods detect crack initiation in materials with contrasting mechanical properties. It shows that wavelet scattering is more sensitive to crack onset and reveals distinct material-specific signatures, supporting smarter in-process defect monitoring in microforming (Dwiyati et al., 2026).

The twenty-sixth, written by Nasution and Kurose, 2026, examines vacancy in Surabaya's inner-city kampungs through street network configuration using space syntax analysis. This study analyzes 16 informal settlements with angular connectivity, integration, and choice measures to identify spatial patterns linked to vacant properties. It shows that vacancy is more likely on streets with lower connectivity but higher global integration and choice, highlighting a trade-off between accessibility and residential privacy (Nasution and Kurose, 2026).

The twenty-seventh, written by Kabdiyono et al., 2026, investigates bamboo leaf ash as a sustainable stabilizer for extremely high-plasticity soils such as bentonite. This study combines compaction, geotechnical testing, and microstructural analysis to evaluate how bamboo leaf ash alters soil plasticity and mineral structure. It shows that Mayan bamboo leaf ash markedly reduces liquid and plasticity limits through pozzolanic reactions, supporting a greener approach to problematic soil stabilization.

The last study, written by Basten et al., 2026, applies a Value Engineering and Risk Assessment (VERA) approach to transform risk mapping in shopping mall construction. This study combines Delphi validation, FAST diagrams, and FMEA-based risk prioritization to identify dominant construction risks and define mitigation strategies.

The role of research practices in supporting collaboration and accessibility in frontier technology remains an area of ongoing consideration. Submissions that contribute to these perspectives are welcome, and we look forward to receiving manuscripts from the research community. Thank you for your interest, and authors are kindly invited to submit their work for consideration.

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