FutureBridge

CHEMICALS, MATERIALS & NATURAL RESOURCES

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25 INNOVATIONS YEARS TO NET-ZERO

A quarter century to build a better future

BRIEFING

Circularity in Silicone Manufacturing

Circular solutions and low-carbon feedstocks are redefining sustainable silicone manufacturing.

Introduction

Silicones are widely used in industries like healthcare, electronics, automotive, and construction due to their thermal stability, flexibility, and durability. However, traditional silicones rely on petroleum-derived feedstocks which contribute to carbon emissions and resource depletion. Their recycling rates also remain low (<5% globally) because of a lack of infrastructure, high cost of recycling and technical challenges, such as chemical stability and inadequate quality of recycled materials.

This Briefing provides an overview of the currently available pathways to achieve sustainability across the silicone value chain. Sustainable raw materials and circular technologies are a key focus.

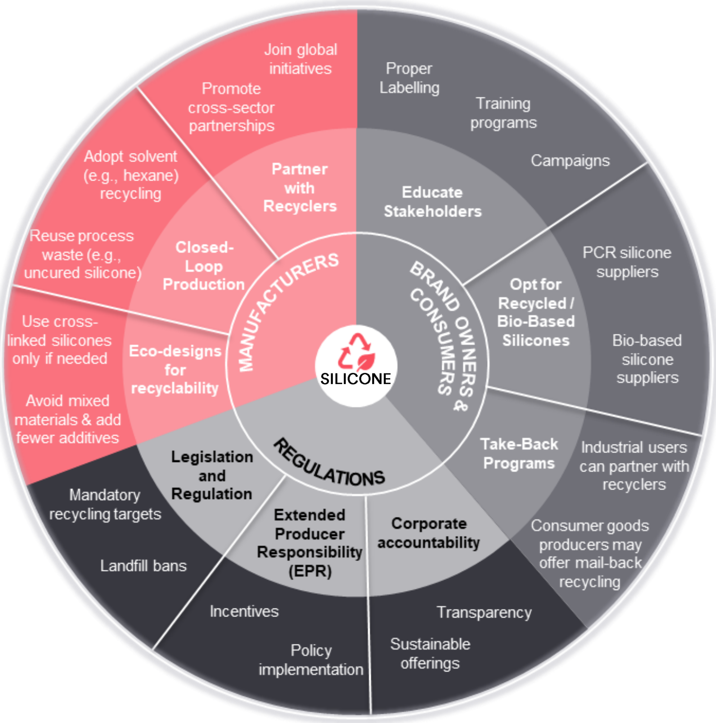
FutureBridge, as a research and advisory partner, supports silicone industry stakeholders in achieving their commercial and sustainability goals which include the implementation of decarbonization strategies.

Silicone Waste Management Ecosystem

To align with sustainability goals and regulatory requirements, the silicone industry must transition towards sustainability. Bio-based feedstocks, eco-designs, closed-loop recycling, and regulatory vigilance are key "must-do's" for silicone producers.

Manufacturers

- Recyclable designs and formats can accelerate adoption of circular solutions. Simplifying chemistries, minimizing multi-component formulations etc. are key enabling approaches.
- Recovering uncured silicone scrap in-house supports waste-reduction; while other harmful chemicals, such as solvents, can be reclaimed and recycled.
- Depending upon in-house waste-types, collaboration with recyclers can be established for appropriate recycling technologies (e.g., chemical recycling for high-purity medical-grade waste or mechanical recycling for seals and gaskets).



Brand Owners & Consumers

- Industrial end-users (automotive, construction etc.) can partner with recyclers to collect end-of-life silicone parts. Consumer goods (bakeware, cosmetics etc.) producers can offer mail-back recycling.
- Appropriate recycling symbols (e.g., "Silicone – Recycle with Specialist Facilities") promote awareness to prevent waste-stream contamination. Hazardous (e.g., cured silicone) and non-hazardous formulations should be highlighted separately.

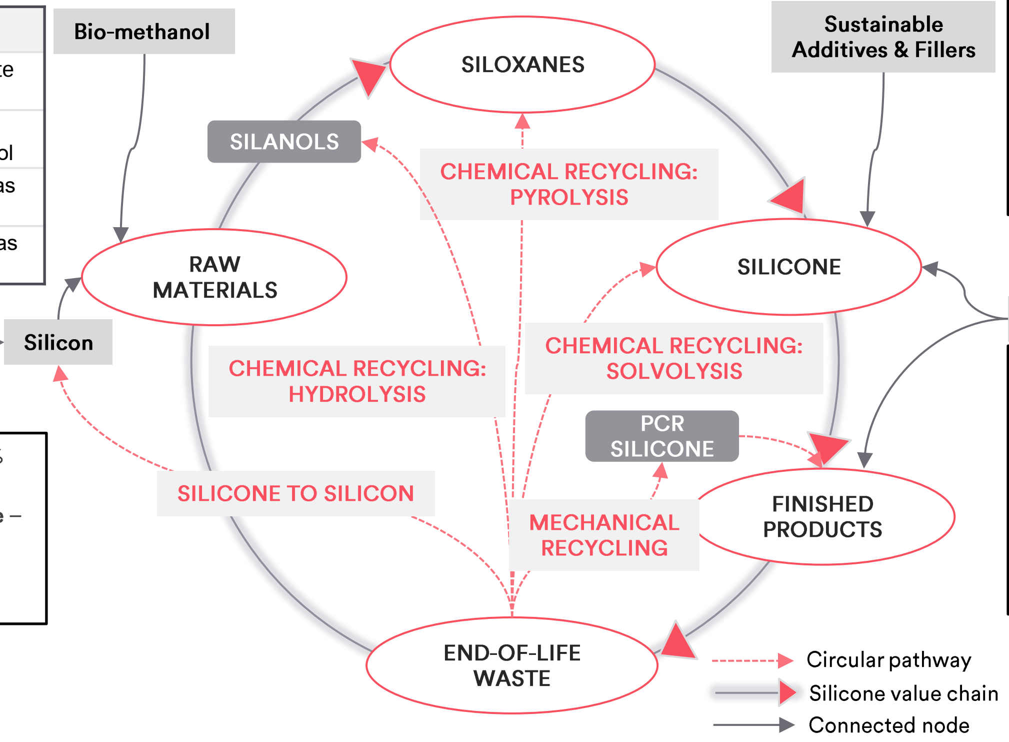
Regulations

- Tax breaks / subsidies could facilitate companies to adopt sustainable production and recycling practices.
- EPR laws can be enforced; requiring manufacturers to take responsibility for the end-of-life disposal of their products.
- Brands can be encouraged to disclose production practices and environmental impact. Targets can be set for Brands to recycle their products.
- Disposal in landfills can be prevented by implementing waste disposal laws.

Sustainability in the Silicone Value Chain

Bio-based silicones offer a sustainable alternative to traditional fossil-based products while advancements in silicone recycling technologies should enable circularity to then include 'non-virgin fossil products'

Feedstock	Production Method
Biomass Gasification	Wood, agricultural waste → Syngas → Methanol
CO_2 Hydrogenation	CO_2 + H_2 (from electrolysis) → Methanol
Anaerobic Digestion	Organic waste → Biogas → Methanol
Algae-based	Algal biomass → Syngas or CO_2 → Methanol



Non-Toxic Catalysts: Replace platinum-based catalysts with greener alternatives where possible

Bio-Based Fillers: Use natural reinforcements like rice husk ash (silica source) or plant-derived additives

Bio-silica

Rice Husk Ash (RHA) – Contains ~90% silica after combustion

Bamboo Leaves & Sugarcane Bagasse – Alternative silica sources

Diatomaceous Earth – Naturally occurring silica from fossilized algae

Waste Reduction & Efficiency

Lean Manufacturing: Optimize production to minimize waste and energy use

Closed-Loop Systems: Reclaim and reuse solvents, catalysts, and by-products

Longer Product Lifespan: Enhance silicone products durability to reduce replacement frequency

The Three Pillars of Sustainable Silicone

The journey to sustainable silicone hinges on three interconnected pillars, transforming its lifecycle.

1. **Sustainable silica** sourced from agricultural waste, like rice husk ash, reduces mining dependence and valorized by-products.

2. **Bio-based/circular methanol** derived from biomass, plastics or captured carbon can replace fossil fuels to decarbonize the silicone molecule's core structure.

3. **Advanced recycling**, particularly chemical depolymerization, closes the loop by breaking down silicone waste into its raw siloxanes for repolymerization into new, high-quality products.

Together, these pillars - **sustainable feedstocks, bio-based carbon, and circular recycling** - create a synergistic ecosystem that minimizes virgin resource extraction, reduces carbon emissions, and eliminates waste to embed silicone within a circular, renewable economy.

Sustainable Silica Manufacturing Pathways

Challenged by cost parity with mined quartz, sustainable silica production routes will be driven by carbon taxes & ESG pressures if market economics and/or scale-up do not yet (or cannot) compete head-to-head

	Agricultural Waste-Derived Silica (Rice Husk Ash, Bagasse, Bamboo)	Recycled Silica from Industrial By-products	Low-Carbon Fused Silica	Bioleaching (Microbial Silica Extraction)
Process technology	**Combustion:** Rice husks burned at 500-800°C → amorphous silica ash (90-98% pure) **Alkali Extraction:** Silica dissolved in NaOH → precipitated with acid	**Geothermal brine:** Silica extracted from wastewater (e.g. Iceland HS Orka) **Steel slag:** Silica-rich waste from steelmaking **PV panel recycling:** Recovered from end-of-life solar cells	**Electric arc furnaces:** (renewable powered) for melting quartz **Plasma-assisted synthesis:** Reduces energy use 30-50%.	**Bacteria/fungi** (e.g. f*usarium oxysporum*): Dissolve silica from low-grade ores **Plant-based extraction:** Some plants (e.g., horsetail grass) hyperaccumulate silica
Advantage	• Circular economy: Uses farming by-products or waste • Lower energy: 3-5x less energy than quartz processing • No mining: Avoids land destruction	• Waste valorization (no new mining) • Often high-purity (e.g., geothermal silica is >99% pure)	• Retains high purity (critical for electronics/pharma) • Scalable with green energy	• Low-energy, ambient temperatures • Works with low-purity ores
Limitations	• Impurities: Carbon, metals (K, Ca) require extra purification • Scalability: Limited by regional feedstock availability	• Limited supply and dependent on other industries as by-product • Contamination risk (e.g., heavy metals can be found in slag)	• High capex for new furnace tech	• Slow process (weeks vs. hours for conventional methods) • Not yet commercialised
Takeaways for silicone producers	✓ **Currently, most advanced sustainable silica production route** ✓ **Silicone producers can access the technology via build, borrow or buy approaches**	✓ **Since this is an emerging technology, investing in recycling partnerships and developing the value chain would be essential for silicone producers**	✓ **Silicone producers can collaborate with fusing technology providers** ✓ **Plasma-assisted process could be explored as it enables the low-carbon silica breakthrough**	✓ **With its commercial viability likely by 2030, silicone producers can consider exploring and evaluation**

Bio-methanol Availability & Takeaways For Silicone Industry

As a key silicone precursor, government policies will be a driver for bio-methanol; silicone manufacturers must align bio-methanol procurement with regional policies to ensure compliance & cost efficiency

REGION	POLICY / REGULATION	REGIONAL TAKEAWAYS FOR SILICONE INDUSTRY
EUROPEAN UNION	**Renewable Energy Directive (RED III)** -Mandates 32% renewable energy in transport by 2030, including bio-methanol -Double-counting for advanced biofuels (e.g., waste-derived methanol) **EU Carbon Border Adjustment Mechanism (CBAM)** -Penalizes fossil-based methanol imports; favouring low-carbon alternatives **Fit for 55 Package** -Subsidizes green hydrogen (critical for CO_2-based methanol)	- Bio-methanol demand will rise in Europe - There shall be higher cost in short-term, but long-term stability is expected assuming carbon pricing comes into effect -Silicone producers will have to secure supply of bio-methanol
USA	**Inflation Reduction Act (IRA)** -$3/kg subsidy for green H_2 → Boosts CO_2-to-methanol economics -Tax credits for carbon capture (45Q) and biofuels **Renewable Fuel Standard (RFS)** -Supports biomass-derived methanol as an advanced biofuel	- There is sufficient bio-methanol availability in the country without price pressure; short- or long-term contracts can be made by silicone producers - US-made bio-methanol should be cost-competitive vs. imports, though tariffs may distort pricing which should then find a new footing - Midwest & Gulf Coast is likely become a bio-methanol manufacturing hub given abundant biomass + CO_2 sources
CHINA	**14th Five-Year Plan (2025 Goals)** -Coal-to-methanol capped, push for green methanol (from biomass/H_2) **National Carbon Trading Scheme** -Forces industries (e.g., chemicals) to adopt low-carbon feedstocks	- Bio-methanol is scaling up, though it must compete with coal-based methanol - Domestic bio-methanol projects are accelerating (state-backed) - Cheap coal-methanol is still dominant (~80% of China's supply)

Silicone Recycling Technology Options

Recycling technologies will play a key role in silicone waste management and enabling circularity; chemical recycling technologies show significant commercial potential although today are at pilot-scale

	MECHANICAL RECYCLING	CHEMICAL RECYCLING			THERMAL RECYCLING (ENERGY RECOVERY)	SILICONE-TO-SILICON
		PYROLYSIS	HYDROLYSIS	SOLVOLYSIS		
Process	Silicone waste (e.g., gaskets, seals, tubing) is shredded, cleaned, and reprocessed into new products. Often blended with virgin silicone to maintain performance.	Waste silicone is heated (400-800°C) in an oxygen-free environment, breaking it down into D4 (cyclosiloxanes)	Water / acid is used to cleave Si-O bonds to afford silanols	Solvents (e.g., supercritical CO_2, ionic liquids) are used to dissolve silicone waste and recover silicones	Involves incineration with energy recovery (silicones have high calorific value). Silica ash can be reused in cement or ceramics	Pyrolysis converts waste silicones into fine silicon particles.
Input waste type	• Rubber mats • Industrial parts • Footwear • Construction materials	• All types of waste • Ideal for medical / electronic-grade silicones	• All types of waste	• Recycling silicone adhesives • Coatings • Medical devices	• All types of waste	• All types of waste
Advantage	• Low-cost • Simple process	• High purity output • Recovered siloxanes used to make new silicones	• High purity output • Mild process conditions	• Selective • Low energy requirement	• Recover waste energy if no alternatives are available	• High-value output (e.g., application in Li battery anodes)
Limitations	• **Downcycling** yields lower-value material for reuse • **Contamination risk:** Requires clean, sorted waste streams	• Energy-intensive • Catalyst (e.g., KOH) requirements may induce complexity	• Slow reaction • Wastewater treatment requirements will increase costs	• Solvent costs • Limited scalability at present	• Not circular (loss of material value) • Emissions control needed (effluents such as SiO_2 and HCl)	• Low yield • Expensive
Readiness	**Commercial**	**Commercial Pilot**	**Laboratory Pilot**	**Laboratory Pilot**	**Commercial**	**Laboratory Pilot**

Key Questions Our Clients Ask Us...

By delivering comprehensive and end-to-end solutions, FutureBridge provides support to key industry stakeholders to de-risk and accelerate their tackling of circularity challenges and seizing of opportunities

- Do you have **a framework / program to monitor and evaluate** a stream of topics around silicon recycling such as potential business opportunities / technology / feedstock sourcing / players / start up / assessment / regulations / etc.?
- Which are the key regulations at global / regional / country level; what are the implications of those regulations in terms of supply-chain maturity and market size opportunity?
- How does the **technology landscape** look like; which are the best-fit technologies?
- How would you **benchmark technologies** and suggest the most relevant technologies basis KPIs such as scale / TRL / complexity / feedstock processing / etc.?
- Which companies would be 'potential fits' to achieve **our inorganic growth related to recycling?**
- How does the overall player ecosystem of technology owners / plant operators look like?
- Which are the **most promising start-ups / partners** for collaboration?
- What are some major business / operating models in this domain?

As the former Chief Scientist of Kimberly-Clark, I worked with FutureBridge as a client for over six years. Their approach consistently impressed me - combining personalized, value-oriented communication with deep industry expertise. They quickly earned our trust through transparency, practical insights, and a strong focus on outcomes.

FutureBridge stood out not only for its ability to understand the nuances of the chemicals industry and consumer products space, but also for the clarity and integrity of its engagement model. Their reputation for innovation, data-driven decision-making, and collaborative culture made them an ideal partner.

That conviction led me to take the next step—not just as a client, but by joining FutureBridge as a Partner to help other companies unlock the same value and accelerate innovation with confidence.

Pete Dulcamara
Former Chief Scientist @Kimberly-Clark
Partner @FutureBridge

Our Chemicals, Materials & Natural Resources Team

Dr Sarah Hickingbottom

VP & Global Practice Head

Sarah brings 20+ years of international experience in research, strategy & scaling innovation for the chemicals, fuels & agricultural industries. She has led a non-profit bioeconomy organization as CEO & was GM at a late-stage bio-based chemicals start-up which gives her a rare combination of sector insight, commercial rigor, policy and sustainability-driven innovation growth leadership.

Rajesh Kumar

Director

Rajesh is a materials expert with 16 years of diverse experience across manufacturing, consulting, and advisory services. With a strong technical foundation and strategic insight, he has successfully driven innovation programs, and business growth in leading organizations.

Click here to discuss strategic pathways for sustainable silicones

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FutureBridge is a techno-commercial consulting and advisory company. We track and advise on the future of industries from a 1-to-25-year perspective.

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