

Chemistry's Role in Malaysia Sustainable Development Progress

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Chemistry's role in Malaysia's progress achieving the United Nations Sustainable Development Goals (SDGs) is reviewed in a special topic article recently published in *Pure and Applied Chemistry* [1]. Readers interested in exploring this topic further, should check out [1] and the references provided therein for more comprehensive details.

Malaysia has started a historic pursuit to mainstream the UN's 17 SDGs and thereby incorporate them into Malaysia's national developmental framework [2, 3]. These initiatives are emphasized by a participatory governance system overseen by the National SDG Council. It is led by the Prime Minister with the support of governmental stakeholders, civil society organizations, and private sector institutions as depicted in Figure 1 [3]. Thus, it is essential to make this approach inclusive to facilitate cooperation and gain a more thorough understanding of how all the goals are interconnected.

The Malaysian government has previously conducted National SDG Symposiums and focus group discussions to engage the stakeholders and enhance their contribution towards the conservation of SDG-related policies and programs. These dialogues have allowed various stakeholders to contribute to the actualization of the SDGs. The engagement of NGOs, and private sectors is imperative as has been taken into consideration by the mapping of the SDs with the Eleventh Malaysia Plan (11MP) to ensure that sustainable development is at the heart of Malaysia's development plan.

Malaysia has also carried out a readiness assessment in terms of data for SDGs and has reviewed where the gaps are in terms of monitoring and reporting on the SDGs. Studying these issues is necessary to establish a solid data set to implement the goals. Resource mobilization through social enterprise, corporate social responsibility (CSR) projects, and public funding within the framework of the 11MP is also an essential aspect of this work. Moving forward, Malaysia continues to support the SDGs, focusing on the decentralisation of the SDG approach by implementing the multi-stakeholder institutional framework at the state level. Such

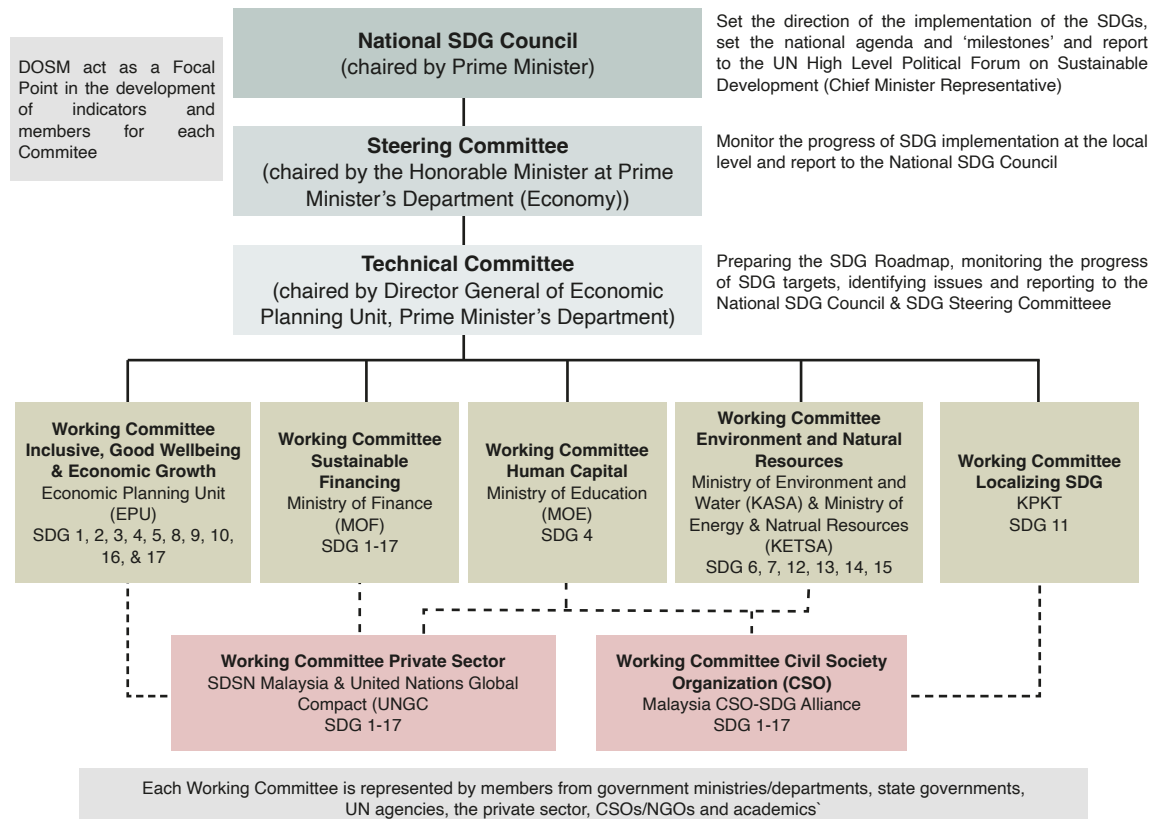


Figure 1: The SDG governance structure in Malaysia [2].

an approach is consistent with Malaysia's commitment and efforts towards the implementation of the SDGs and the development of sustainable solutions for the rakyat.

In this effort, chemistry remains central to the task of identifying key challenges and opportunities for advancing sustainability. This article explores how chemistry can drive Malaysia's progress towards achieving the SDGs to an environmentally conscious, societally safe, and economically sustainable future.

SDG 3: Good Health and Well-being

SDG 3 emphasizes the importance of good health and well-being for all, a vision which Malaysia has ambitiously embraced. This goal aims to ensure healthy lives across all ages and tackle challenges such as communicable diseases and the need for innovative treatments. Most initiatives that deal with improvements in the quality and enhancement of Universal Health Coverage in Malaysia are led by the Ministry of Health, Malaysia. Target 3.8 emphasizes Universal Health Coverage (UHC), including financial risk protection, access to quality health services, and access to essential medicines.

Malaysia possesses one of the most efficient healthcare systems in Southeast Asia, achieving UHC through heavy government subsidies and large investments in healthcare infrastructure. Consequently, infant and maternal mortality rates have fallen remarkably. The maternal mortality rate has decreased from 43 per 100 000 live births in 1990 to 21.1 in 2020. Neonatal mortality rates have fallen, reflecting improvements in health services, prenatal and postnatal care, and public awareness. Despite such advances, disparities persist in healthcare access, particularly in rural areas and among marginalized communities; targeted interventions will be required to narrow the gap. This, in turn, challenges health care financing in the task of balancing resources with quality while ensuring cost-effectiveness.

Target 3.9 aims to substantially reduce the number of illnesses and deaths from hazardous chemicals and pollution, by demonstrating that chemistry can be a positive force to improve health. Proper management of pollutants and chemicals is essential to public health.



Further investment in research and development will help nurture new innovations in medical technology and pharmaceuticals.

Chemistry is playing an important role in medical research, starting from the development of drugs up to monitoring the environment; both are important in disease prevention and control, ultimately contributing to a healthier and more resilient society.

SDG 4 & SDG 6: Quality Education & Clean Water and Sanitation

Malaysia has been making progress in achieving both SDG 4 (Quality Education) and SDG 6 (Clean Water and Sanitation), and chemistry is one of the key enablers. Malaysia has incorporated Education for Sustainable Development into the school curriculum since the 1990s, showing commitment towards environmental awareness and global citizenship. Chemistry curriculum emphasizes green experiments, while co-curricular activities like Nature Clubs further support environmental education. The efforts have been scaled up by NGOs such as Water Watch Penang, the Global Environmental Centre, and Clean International through school partnerships for water conservation awareness and various education outreach activities.

In the realm of SDG 6, Malaysia has developed a robust water treatment infrastructure, with 344 water treatment plants employing both conventional (Figure 2, [4]) and advanced methods. Chemical processes such as coagulation, flocculation, and chlorination ensure clean water for distribution. Advanced technologies (Figure 3, [5]), including ozonation and titanium dioxide photocatalysts, effectively tackle organic pollutants and heavy metals.

Government agencies like the Department of Irrigation and Drainage and private corporations such as Intel Malaysia contribute significantly to sustainable water management through education, innovation, and conservation initiatives. Malaysia's adoption of the Integrated Water Resources Management (IWRM) strategy and reforms under the Water Services Industry Act 2006 underscore the nation's commitment to sustainability. Through the synergy of NGOs, government agencies, and corporations, Malaysia demonstrates how chemistry can bridge education and environmental

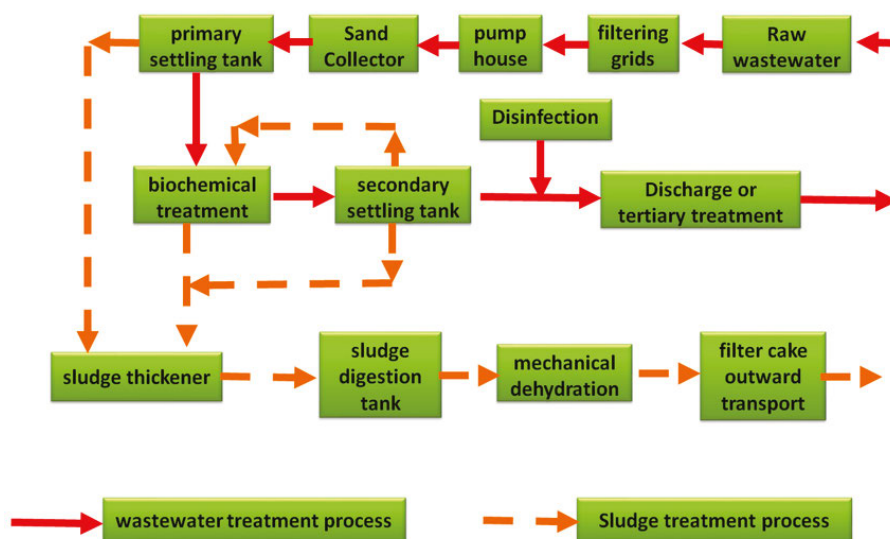


Figure 2: Typical process flow diagram of a wastewater treatment plant (WWTP) [4].

stewardship, ensuring a sustainable future for both its people and water resources.

SDG 7: Affordable and Clean Energy

Malaysia's power consumption is projected to increase threefold by 2050 due to electrification and improved living standards. In achieving carbon neutrality by 2050, Malaysia is transitioning to renewable energy (RE) and clean energy sources. The National Energy Policy (NEP) 2022-2040 targets a 31% RE capacity mix by 2025 and 40% by 2035. Supporting frameworks like the National Energy Transition Roadmap (NETR) launched in August 2023 focuses on six key areas, namely, RE, low-carbon mobility, hydrogen, bioenergy, carbon capture, and energy efficiency.

Solar energy leads the RE sector, with installed capacity growing from 0.1 GW to 2.6 GW since 2011 and further expansion on initiatives like Net Energy Metering and Feed-in Tariff programs have driven cost reductions and increased solar competitiveness. As of 2023, Malaysia's installed RE capacity reached 25%, progressing towards its 31% goal. Biomass, mainly from palm oil waste, also plays a role, supported by initiatives like the National Biomass Action Plan (NBAP) 2023 – 2030 and biodiesel programs. The transport sector, responsible for 25-30% greenhouse gas (GHG) emissions, is undergoing reforms through the Low Carbon Mobility Action Plan (LCMB). This target is promoting public transport, expanding electric vehicle charging infrastructure to support broader EV adoption, and developing hydrogen energy hubs to reduce GHG emissions.

Challenges persist, including RE intermittency and the need for battery energy storage systems (BESS) to stabilize the grid. Malaysia intends to adopt 500 MW of BESS to enhance energy reliability. Collaborative efforts, advanced green technologies, and improvement in regulatory are essential to drive the energy transition. Initiatives such as the Bursa Carbon Exchange will greatly contribute to sustainable development through facilitation of carbon credit transactions. Thus, innovation and partnership are the keys in the journey of Malaysia toward net zero carbon emission for economic and environmental advancement by 2050.

SDG 9: Industry, Innovation, and Infrastructure

Chemistry underpins Malaysia's efforts to develop resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation. The chemical industry in Malaysia covers a wide range of sectors, from petrochemicals, oleochemicals, and specialty chemicals to pharmaceuticals, semiconductors, and quantum computing.

The semiconductor industry, a cornerstone of Malaysia's economy, heavily relies on advancements in chemical processes. With the presence of multinational companies such as Intel, Texas Instruments, and Infineon Technologies, Malaysia has become a part of the key global supply chain for semiconductor. Innovations in chemical engineering are crucial in the development of high-purity silicon wafers, photolithographic chemicals, and advanced materials like gallium nitride and silicon carbide for next-generation chips.

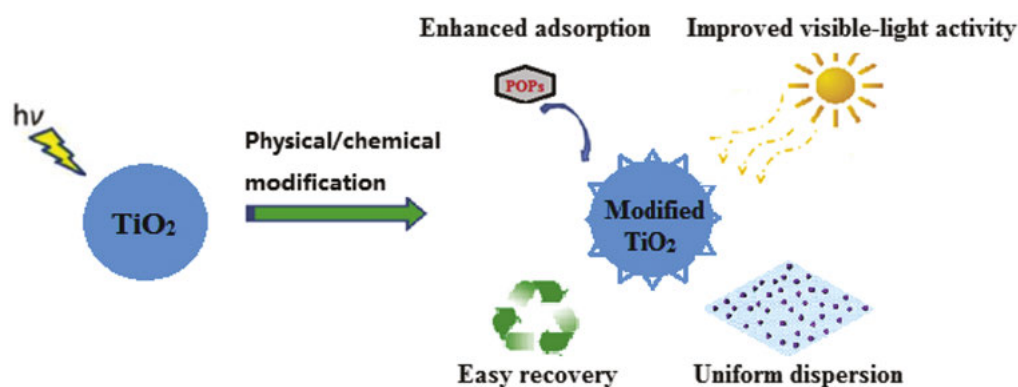


Figure 3: Advanced wastewater treatment processes using ozonation and titanium dioxide photocatalysts [5].

Collaborations between industry and academia, such as Universiti Sains Malaysia (USM), Universiti Malaya (UM), Universiti Teknologi MARA (UiTM) with Infineon, have driven research in developing sustainable and energy-efficient semiconductor materials. This sector contributed significantly to Malaysia's electrical and electronics industry, which accounted for 5.8% of GDP in 2023, with export earnings projected at RM495 billion by 2025. Sustainable practices include water recycling and introduction of green solvents could be incorporated into greener semiconductor manufacturing to reduce its environmental footprint.

Another cutting-edge technology merging with chemistry is the quantum computing sector in Malaysia. Quantum chemistry, which involves simulating molecular systems using quantum computers, is revolutionizing drug design, material discovery, and solutions to environmental issues. Malaysia's collaboration under Center of Excellence in Quantum Information Science and Technology (COE QiST), Universiti Malaya with Xanadu, a Canadian quantum computing company, underlines the commitment of the country to integrating quantum technologies into its ecosystem. The collaboration will develop algorithms in molecular modeling that will increase efficiency in the design of new materials for batteries, semiconductors, and pharmaceuticals. This initiative aligns with Malaysia's vision for a highly skilled workforce in high technology and its positioning to become the leading player in quantum innovation within Southeast Asia.

Specific projects such as Petronas's ventures into quantum-enhanced materials discovery demonstrate how chemistry and quantum computing converge to solve some of the challenges facing energy storage and green energy solutions today. These efforts also complement the strides Malaysia is making in the oil and gas industry, which contributes RM300 billion to the GDP annually, and the palm oil industry, with exports valued at approximately RM137 billion in 2022.

Chemistry is leading the transformation through sustainable chemical innovations in production processes for the benefit of both industries.

The palm oil industry, a vital sector in Malaysia, also illustrates how chemistry can contribute to sustainability. Efforts include converting palm oil waste into biofuels and bioplastics, reducing reliance on fossil fuels and mitigating environmental degradation, while also supporting SDG12 (Responsible Consumption and Production). Such innovations reduce the carbon footprint and further the circular economy, hence promote climate action due to deforestation and land-use change.

Water resource management is another critical area where chemistry is having a major impact. Advanced chemical technologies in water treatment, such as green membrane filtration and chemical adsorption processes, help improve access to clean water and sanitation, hence contributing to clean water and sanitation sustainable goals. These efforts protect marine biodiversity, aligning with SDG14 (Life Below Water) by preventing industrial pollutants from entering aquatic ecosystems.

SDG 11: Sustainable Cities and Communities

As the urban population of Malaysia is growing, sustainable urban development is crucial to meet the needs of 78.2% of its residents residing in cities while addressing environmental, social, and economic sustainability. In the year 2020, Selangor was reported as the most populous state in Malaysia, comprising a population of 6.7 million, whereas Sabah had the highest rural population, amounting to 1.55 million. SDG 11 focuses on developing cities to meet the immediate needs of residents while promoting environmental, social, and economic sustainability. Active participation and partnership of stakeholders is required, including national and state governments, local councils, the private sector, the public, and individuals are essential to

create a sustainable city for all.

Chemistry plays an important role in the achievement of SDG 11. Analytical chemistry and instrumentation are essential for monitoring air and water quality, ensuring compliance with environmental standards, and safeguarding public health. Wastewater treatment processes rely on chemistry to remove pollutants, making treated water safe for environmental release. Life Cycle Assessments (LCA) help evaluate the environmental impact of materials and processes, promoting sustainable resource use and reducing environmental burdens.

The 12 Principles of Green Chemistry guide the development of eco-friendly materials and processes, reducing hazardous material use and waste generation. For instance, creating weather-resistant materials can help cities become more resilient to natural disasters like floods and landslides, while promoting sustainable raw material consumption and waste management. Chemistry also contributes to the development of alternative fuels, electric vehicles, and chemical recycling technologies, reducing air pollution and traffic congestion. Encouraging public transport, walking, and cycling further reduces greenhouse gas emissions and promotes health. Green spaces and communal areas foster mental well-being and social interactions, while sustainable urban design ensures inclusive access to healthcare, education, and job opportunities. Initiatives like Kuala Lumpur's Car-Free Morning highlight the co-benefits of reducing air pollution and encouraging physical activity.

In collaboration with stakeholders, chemistry underpins innovations that drive urban sustainability, mitigating climate change impacts while fostering healthier, more resilient communities.

SDG 12: Responsible Consumption and Production

Malaysia's rapid urbanization and economic growth have driven increased consumption and waste generation, posing significant environmental challenges. Malaysia has established frameworks like the National Solid Waste Management Policy and Solid Waste and Public Cleansing Management Act 2007 to promote recycling and reduce waste. Despite efforts, the recycling rate is only 31%, trailing behind regional neighbors. The government aims to achieve a 40% recycling rate by 2025. Chemistry-driven innovations can help Malaysia meet this target by improving recycling infrastructure and waste separation practices. Municipal Solid Waste (MSW) management remains a challenge, with food waste constituting 44.5% of MSW

in 2016. Inefficient waste management infrastructure has resulted in environmental crises, such as the "Sungai Kim Kim Chemical Waste Pollution incident" in 2019. Chemistry is crucial in advancing sustainable practices and addressing these issues in line with SDG 12.

Chemistry enables the efficient recycling of plastics, metals, and paper by breaking down materials into their fundamental components and recovering valuable chemicals from hazardous waste. Innovations like biodegradable plastics and chemical recycling technologies reduce plastic pollution and minimize landfill dependency. The knowledge of Chemistry is incorporated in developing sustainable materials like biodegradable plastics and promotes life cycle assessments to measure environmental and economic impacts. It is worth noting that biotechnology programs under the National Biotechnology Policy 2.0 and the Bioeconomy Transformation Program focus on research and innovation in biomaterials that may lead to sustainable industrial practices. Thus, Chemistry plays a fundamental role in achieving responsible consumption and production through research, innovation, and policy support, ensuring a balance between environmental sustainability and economic growth.

SDG 13 Climate Action

Malaysia must address climate challenges from rising temperature and extreme weather to sea-level rise through a dual approach of adaptation and mitigation. The country is investing in climate-resilient infrastructure, enhanced drainage systems, green urban projects, and resilient transport networks to reduce these risks. Besides, biodiversity conservation helps to enhance ecosystem resilience and provide services such as carbon sequestration and water purification. Community engagement furthers resilience and sustainable development.

Chemistry takes center stage in Malaysia's climate mitigation strategy through innovation and the development of sustainable solutions to address environmental challenges. These include the development of renewable energy, carbon capture and storage (CCS) systems, and the decomposition of greenhouse gases. CCS technology captures carbon dioxide (CO₂) emissions from industrial processes and power plants for storage in geological reservoirs or conversion into products like methanol. Petronas, a leading Malaysian energy company, has outlined a decarbonization roadmap utilizing CCS technologies, aligned with the NETR. Additionally, innovative catalytic processes, such as using hydrated K⁺ ions and TiO₂ photocatalysts, are

being explored to decompose nitrous oxide (N_2O), a potent greenhouse gas, effectively.

The 2023 ACS Global Innovation Imperatives (ACS Gii) in Malaysia shed light on computer technology applications in chemistry for better air quality management. It focuses on building community resilience in response to climate conditions and further strengthens national goals related to climate policy.

Malaysian chemical research focuses on novel materials to tackle greenhouse gases and volatile pollutants. The country implements various strategies such as using TiO_2 coatings on infrastructure to reduce N_2O emissions and incorporating advanced catalysts that demonstrate a commitment to sustainable solutions. These innovations, combined with biodiversity conservation and infrastructure resilience, demonstrate Malaysia's commitment to addressing climate challenges. Malaysia endeavors through the application of chemical science along with community action towards a sustainable and climate-resilient future.

SDG 14: Life Below Water

As a coastal nation, Malaysia is deeply tied to its marine biodiversity, yet it faces significant challenges from marine pollution, including microplastics, oil spills, pesticides, and sewage effluent. To combat these issues, Malaysia's Department of Environment (DOE), under the Ministry of Natural Resources, Environment, and Climate Change (NRECC), has been monitoring marine water quality since the 1970s using chemical analyses. Backed by legislation such as the Environmental Quality Act of 1974, the DOE enforces pollution control to safeguard marine ecosystems.

As such, Chemistry is at the forefront in Malaysia's marine conservation efforts. For example, coral reefs, vital to marine biodiversity, are severely impacted by ocean acidification caused by carbon dioxide (CO_2) emissions, which disrupt nutrient cycling and calcification processes. Recognizing this, the Department of Marine Park Malaysia and Reef Check Malaysia initiated coral restoration programs in 2011 following a mass bleaching event. The emerging field of marine biotechnology further highlights chemistry's importance. Malaysia's diverse marine ecosystems, particularly in Sabah, offer potential for discovering marine natural products (MNPs)—bioactive compounds with unique chemical properties that hold promise for pharmaceuticals, biotechnology, and environmental applications. By leveraging chemistry for pollution monitoring, coral reef restoration, and marine biotechnology, Malaysia is actively advancing SDG 14 (Life Below Water). Through increased regulatory measures and sustainable

practices, Malaysia demonstrates its commitment to preserving marine biodiversity, reducing pollution, and ensuring a sustainable ocean environment for future generations.

SDG 15: Life on Land

SDG 15 focuses on the conservation, restoration, and sustainable use of terrestrial ecosystems; sustainable management of all types of forests; and halting biodiversity loss. Malaysia is one of the world's 17 megadiverse countries. It measures 329,613 km^2 and more than 60% of Sabah and Sarawak are covered by forests while in Peninsular Malaysia, over 44.7% of the land is covered with forests. The incredible richness in biodiversity comprises an estimated 15,000 species of vascular plants, 306 mammal species, and 742 bird species among many others in most other taxa.

Malaysia steers its path of conservancy through laws such as the Wildlife Act, the Forestry Act, and the National Biodiversity Policy 2015–2025. Malaysia has pledged to maintain at least 50% of its land under forest and tree cover during the Rio Summit in 1992 and has shown commitment to this pledge by maintaining 57.9 % of forest cover as of 2022. At global standing, Malaysia has become a part of various international environmental instruments in pollution, climate change, hazardous waste management, ozone layer protection, and many others. Various steps have been implemented in the local landscape including key elements of biodiversity management such as bioprospecting; nature-based tourism; and endangered species protection. Inevitably, there are challenges ahead, most of all with the heavy burden of deforestation largely attributed to agricultural activities and urban development.

The traditional chemical innovations have contributed much to improving the quality of life, however, they have largely ignored the environmental impact. Hence, a move to sustainable or green chemistry is required that emphasizes product and process design with reduced hazards but equal performance. This would require a new set of criteria for measuring performance where environmental factors are included. In line with this, by incorporating sustainable practices (as recommended by Zimmerman *et al.*; Figure 4) into the framework of chemical research, chemists can avoid pollution and restore ecosystems, which correspond to Malaysia's objective under SDG 15, while aiding in the country's commitment to the conservation of biodiversity.

SDG17: Partnerships for the Goals

Malaysia's success in sustainable development is deeply rooted in its collaborative approach. Partnerships

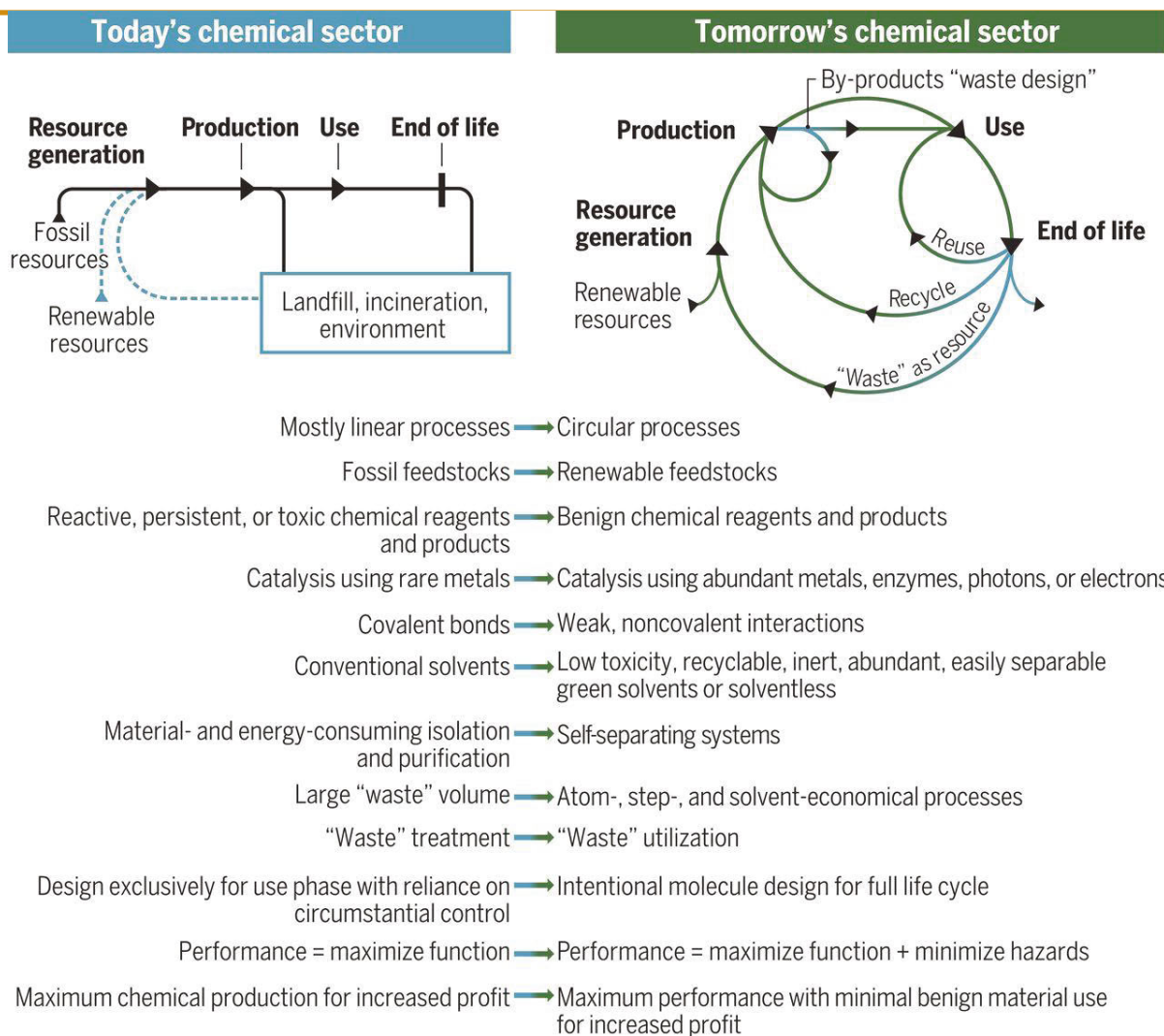


Figure 4: Characteristics of today's and tomorrow's chemical sectors.

have been integral to advancing semiconductors, quantum computing, and other key industries. These collaborations also drive progress across environmental sustainability, health, and energy sectors. For example, Malaysia's participation in the Regional Comprehensive Economic Partnership (RCEP) has strengthened trade ties and technological collaborations with countries like Japan, South Korea, and China, fueling advancements in semiconductor manufacturing. This partnership has enhanced the region's collective capability to develop sustainable technologies that support industry, innovation, and infrastructure.

In the quantum computing domain, the partnership between Universiti Malaya under Center of Excellence in Quantum Information Science and Technology (COE QiST), Xanadu, and MyQI (Malaysia Quantum Initiative) serves as a model for cross-border collaboration. This initiative focuses on creating educational programs and

practical workshops to upskill researchers and industry professionals, enabling Malaysia to develop a quantum-ready workforce. Additionally, collaborations with institutions like the Quantum Technology and Future Computing Group (QTFT.org) have further bolstered Malaysia's capacity for quantum research, emphasizing the synergy between chemistry and computational science. These partnerships have direct implications for SDG13: Climate Action, as quantum-enhanced simulations can optimize clean energy systems and reduce industrial emissions.

Partnerships with the services sector, which accounted for 59.2% of Malaysia's GDP in 2023, are also crucial. Collaborations with global firms in ICT and tourism sectors have spurred innovation in sustainable practices, especially in chemical applications for infrastructure development and energy efficiency. These projects contribute to building Sustainable Cities and

Communities (SDG11) through green infrastructure and low-emission building materials.

Renewable energy initiatives also benefit from international partnerships. Collaborations between local companies and global firms aim to enhance solar energy technologies, bioenergy production, and hydrogen storage, directly supporting affordable and clean energy. Petronas's development of quantum computing applications for energy solutions, including hydrogen fuel storage, reflects Malaysia's leadership in sustainable energy research.

Outlook

Malaysia has consciously positioned itself in line with the UN SDGs by emphasizing the four areas of chemistry, education, partnership, and engagement. Due to the disparity of cultures, society, and economy in Malaysia, it is important to have local participation in combating global issues such as climate change. Community engagement in local climate change adaptation and mitigation taps into local support, knowledge, and inputs developing local ownership and solutions. However, drawbacks like the absence of awareness, constraints in education and the economy, and regulatory problems hamper the progress of green chemistry. This is because the different stakeholders fail to understand the advantages that come with green chemistry. Large initial investment is also a challenge that has been observed in the process of implementation. Furthermore, current policies and regulations do not facilitate or require green chemistry practices to be adopted on a large scale.

Several steps are required to address these issues. A strategic course is to give incentives for green chemistry, formulate regulations minimizing the exposure of hazards, and create forums for information sharing among stakeholders and the public on potential hazards. Interventions with government sectors, educational institutions and communities could enhance making the cities safe, clean, livable, resilient, and sustainable.

With these aspirations, Malaysia aims to unlock existing opportunities and overcome barriers to achieve the sustainable development goals set by the country for a green future. Grounded in chemistry and cooperation with various communities, Malaysia is committed to creating a sustainable future for everyone. 🏡

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