Green Chemistry and Functional Nanomaterials: Sustainable Innovation at Qatar University

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Introduction

Sustainability has become one of the defining scientific challenges of our time. Modern industries increasingly require materials and technologies that are not only efficient and high-performing but also environmentally responsible. From water treatment and energy production to healthcare and industrial processing, researchers worldwide are seeking greener alternatives that reduce waste, minimize environmental impact, and support long-term sustainability.



Figure 1: Overview of the major research themes in Green Chemistry Laboratory at Qatar University.

At Qatar University, our research group focuses on developing advanced functional materials and sustainable chemical technologies inspired by the principles of green chemistry. By integrating nanotechnology, materials science, polymer chemistry, and surface engineering, we aim to design smart systems that address real-world challenges in oil and gas, environmental remediation, water purification, food security, and precision medicine (Figure 1).

The Lab's Role in Green and Sustainable Chemistry

Our research focuses on the design of environmentally friendly materials with enhanced functionality, stability, and recyclability. A major part of our work involves developing biodegradable polymers, phosphonate-functionalized materials, magnetic nanocomposites, and mesoporous nanostructures for sustainable industrial and biomedical applications.

The group works extensively with superparamagnetic iron oxide nanoparticles (SPIONs), mesoporous silica nanoparticles, phosphonated polymers, amino acid-based inhibitors, and bio-derived polysaccharides such as alginic acid and inulin. These materials offer tunable surface chemistry, high adsorption capacity, magnetic responsiveness, and improved environmental compatibility compared to many conventional chemical systems.

Through interdisciplinary collaboration, our goal is to bridge advanced materials research with practical technologies that contribute to cleaner industrial processes, reduced chemical waste, and more sustainable engineering solutions. Representative research activities and laboratory-developed materials are shown in Figure 2.

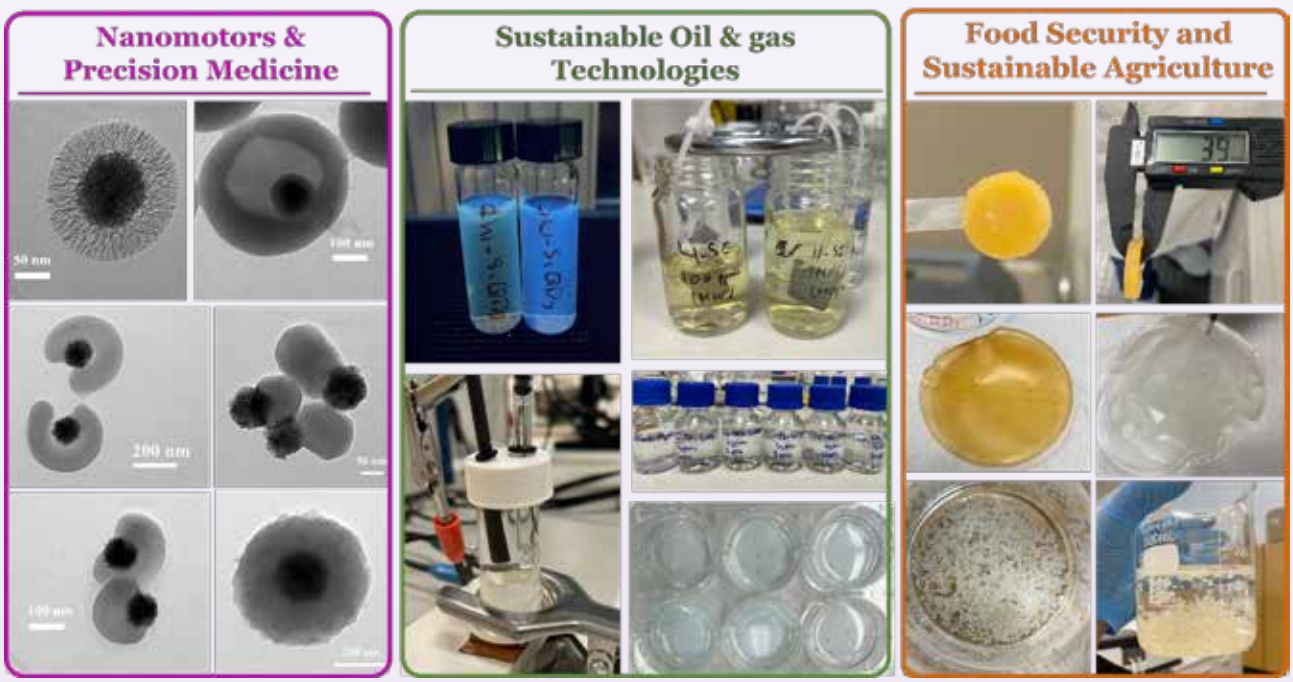
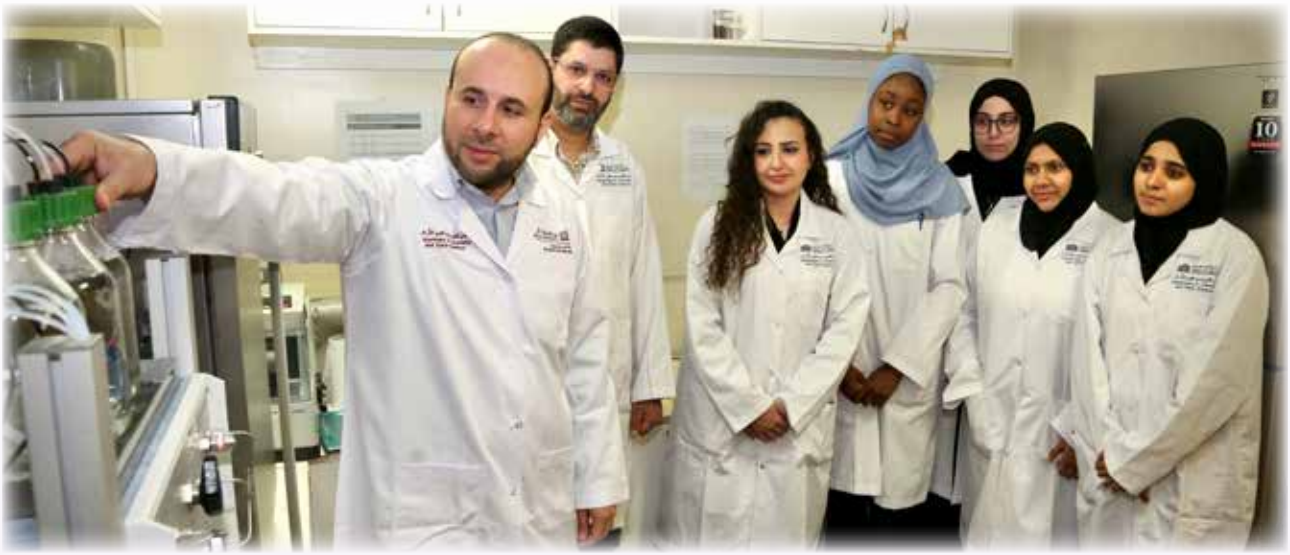


Figure 2: Representative images highlighting ongoing research activities in the laboratory, including mesoporous nanostructures, sustainable oil and gas technologies, and food security and sustainable agriculture applications developed at Qatar University.



Research team members at Qatar University during laboratory activities.

From left to right: Dr. Mohamed Mady, Dr. Showkat Jani, Ranim Eyad, Adilla Pires, Maha Abouseeda, Rinsha Basheer, and Shana Farhath.

Sustainable Oil and Gas Technologies

One of the major research directions of the Green Chemistry Laboratory focuses on environmentally friendly technologies for the oil and gas industry. Mineral scale deposition and corrosion remain among the most significant operational challenges affecting pipelines, desalination systems, and industrial equipment. Conventional inhibitors are often associated with limited biodegradability and long-term environmental persistence, motivating the search for greener alternatives.

To address these challenges, our group developed several biodegradable and dual-functional materials capable of simultaneously controlling scale formation and corrosion. These include dicarboxylated alginic acid, dicarboxylated inulin, phosphonated inulin, and phosphonate-functionalized amino acids designed for harsh industrial environments.

These materials demonstrated effective inhibition against carbonate, sulfate, and silicate scales while also improving corrosion protection under saline conditions. Compared to conventional oilfield chemicals, these systems offer improved environmental compatibility and support more sustainable industrial operations.

Another important direction involves recyclable magnetic nanomaterials based on SPIONs coated with environmentally friendly polymers such as polyaspartate and poly (4-styrenesulfonic acid-co-maleic acid). These magnetic systems can be separated and recovered using external magnetic fields, reducing chemical discharge and supporting circular process strategies.

Our group also investigates mesoporous silica and silica nanoparticles functionalized with phosphonate-based inhibitors for improved gypsum and calcite management. These studies highlighted the importance of nanostructure design and surface chemistry in enhancing inhibitor performance and long-term process stability.

This research direction is led by Dr. Mohamed F. Mady and Dr. Showkat Ali Ganie, with contributions from Adilla Pires and Zainab Baloochi, focusing on sustainable oilfield chemistry, scale and corrosion control, and the development of environmentally friendly inhibitor systems.

Smart Materials for Environmental Sustainability

Beyond oilfield chemistry, our research explores multifunctional nanomaterials for environmental remediation and sustainable water treatment. We develop magnetic nanocomposites capable of removing heavy metals and contaminants from water through adsorption and magnetic separation processes.

These materials combine a high surface area, tunable surface functionality, and magnetic

recoverability, enabling efficient pollutant removal while minimizing secondary waste generation. Our work additionally includes ecotoxicity studies to evaluate the environmental safety and biological compatibility of newly developed nanomaterials.

We also developed bio-derived antimicrobial materials based on quaternary ammonium-functionalized cellulose with enhanced antimicrobial activity, thermal stability, and free radical scavenging capability. Such polymeric systems offer promising opportunities for environmentally safer industrial and biomedical applications.

Research in this area includes contributions from Rinsha and Shana, with a focus on environmental nanotechnology, smart materials, and polymer-modified systems.

Food Security and Sustainable Agriculture

Our laboratory develops sustainable materials for food security and agriculture, particularly for water-scarce environments. Our research focuses on green artificial soil systems based on biodegradable chitosan, Qatari nanoclay, and smart functional coatings to improve water retention and crop productivity.

We developed environmentally friendly nanoclay–polymer systems with enhanced moisture retention, mechanical stability, and potential applications in sustainable agriculture and precision farming. Our work also includes smart humidity-responsive coatings and biodegradable composite materials for advanced agricultural and environmental applications.

Zainab Baloochi and Dr. Farah El-Makaty contribute to the development of environmentally friendly nanosystems and smart materials for sustainable agriculture and food security applications.

Nanomotors and Precision Medicine

The Green Chemistry Laboratory is also actively investigating mesoporous silica micro/nanomotors for advanced biomedical and precision medicine applications. These smart nanosystems combine controlled motion, cargo-loading capability, and multifunctional surface engineering for targeted therapeutic delivery.

Mesoporous silica nanomotors possess highly tunable pore structures and large surface areas that allow efficient loading of drugs and functional molecules. By integrating magnetic components and responsive surface modifications, these systems may contribute to future precision nanomedicine technologies and controlled therapeutic delivery platforms.

In parallel, our research explores engineered mesoporous nanostructures with tailored architectures for multifunctional applications across healthcare, catalysis, and advanced materials engineering.

Research on nanomotors and mesoporous nanostructures is conducted collaboratively within the group, with contributions from Dr. Farah El-Makaty and Ranim Eyad, focusing on advanced nanomaterials and precision medicine applications.

Looking Ahead

Figure 3 showcases selected research directions and recent scientific contributions from our group. The included QR codes provide direct access to representative publications for further exploration of the research. Through the integration of green chemistry, advanced nanotechnology, and materials engineering, our research focuses on developing sustainable solutions for challenges related to energy, water treatment, healthcare, food security, and environmental sustainability. Together, these studies reflect our ongoing commitment at Qatar University to advancing environmentally responsible materials and innovative technologies for a more sustainable future.

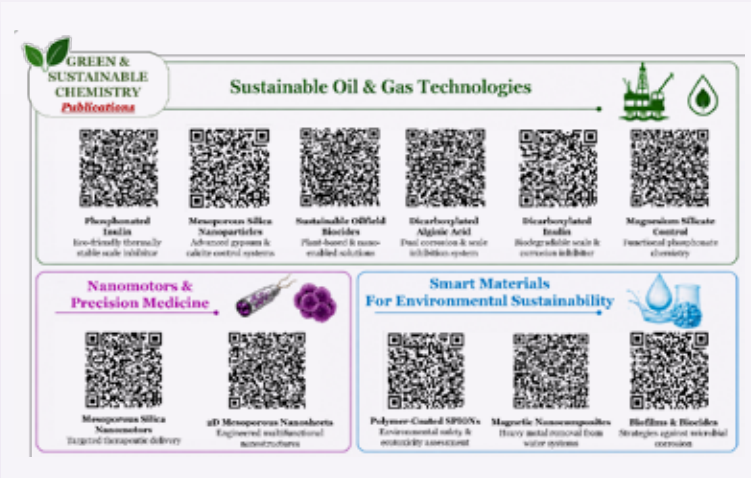


Figure 3: Selected recent publications from the research team, organized according to major research themes, including sustainable oil and gas technologies, nanomotors and precision medicine, and smart materials for environmental sustainability.