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# Nano-catalysts: Key to the Greener Pathways Leading to Sustainability

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Industrial chemistry in the new millennium is widely embracing the concept of "green chemistry" to meet the fundamental scientific challenges of protecting the human health and environment while maintaining commercial success. This emerging area of *Green Chemistry* is defined as "the utilization of a set of principles that reduces or eliminates the use or generation of hazardous substances in the design, manufacture, and application of chemical products" and envisages minimum hazard as the performance criteria while designing new chemical processes. One of the thrust areas for achieving this target is to explore the generation of efficient catalytic processes, particularly nano-catalysis [1]. The desired approach may encompass alternative activation methodology, such as mechanochemical mixing, photocatalysis, microwave-, and ultrasonic irradiation [2]. Additionally, the strategy has to follow "*benign by design*" principles and make an effort to utilize renewable resources wherever possible [3].

In the catalysis domain, the generation of engineered nanomaterials represents a major breakthrough in material science and nanotechnology-based materials. The effort is to develop eco-friendly synthetic strategies to prepare these nanomaterials via routes that use benign reagents rather than the hazardous substances normally used. The sustainable synthetic activity for the preparation of nanoparticles, as an example, may involve the use of vitamins $B_1$, $B_2$, C, and tea and wine polyphenols [4], which function both as reducing and capping agents. This obviates the need to use toxic reducing agents, such as borohydrides or hydrazines. These extremely simple and aqueous green synthetic methods generate bulk quantities of nano-catalysts without the need for large amounts of insoluble templates [5] and have found numerous applications in catalysis [1].

Microwave (MW) technology is emerging as an alternative energy source powerful enough to accomplish chemical transformations in minutes, instead of hours or even days. In the context of nano-catalyst synthesis, the use of microwaves is more relevant when the realization of the material properties is based solely on the size and shape; the control over the synthetic methodologies is critical. This is because the growth of the materials in nanoscale is largely dependent on the thermodynamic and kinetic barriers in the reaction as defined by the reaction trajectory and is influenced by vacancies, defects, and surface reconstructions. In addition to greener synthesis, the recyclability and reuse aspects are very significant especially when it comes to using rare and precious catalysts. Numerous eco-friendly applications in catalysis have been addressed via magnetically recoverable and recyclable nano-catalysts for reduction, oxidation, and condensation reactions [1]; it has already made a tremendous impact on the development of green chemical pathways [2].

Synthetic processes using alternative energy input in combination with nano-catalysts shorten the reaction time that eliminate or minimize side product formation [2]. This concept is already finding acceptance in the syntheses of pharmaceuticals, fine chemicals, and polymers and may pave the way towards the greener and more sustainable approach to chemical syntheses. Newer developments on these themes, especially involving benign reaction media such as water and Polyethylene Glycol (PEG), in conjunction with photo activation [3], MW and ultrasonic irradiation, and/or ball-milling under solvent-free conditions, may help realize sustainable pathways for chemical synthesis and transformations, including the generation of novel nano-catalysts.

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