Heterogeneous catalysis is involved in the manufacture of most finished products from pharmaceuticals to electrical devices. Catalytic processes are inherently green, yielding high atom efficiencies; however, catalyst manufacturing processes have changed little in the last 50 years.

For many mixed oxide or oxide-supported metals, a catalyst precursor is formed by precipitation, hydrothermal synthesis, or grinding and heating; this precursor is then subsequently reprocessed by a heat treatment coupled possibly with a redox step to produce a finished material that can be formed into suitable shapes.

The process is energy intensive, uses large amounts of solvents and produces copious amounts of waste products. A paradox of catalysis, which is perceived to be green when it is not!

The Cardiff team, led by Professor Graham Hutchings, has developed the use of supercritical CO$_2$ as the precipitating medium in catalyst manufacture, producing a number of high activity catalysts via this process.

This is exemplified by the following examples:

**AMORPHOUS VANADIUM PHOSPHATE (VPO)**

The new route using supercritical CO$_2$ as an anti-solvent, is illustrated for vanadium phosphate (VPO) catalysts below: The amorphous microspheroidal VPO produced was found to be to be 3-4 times more active than comparable crystalline VPO catalysts for the selective oxidation of $n$-butane to maleic anhydride and, furthermore, does not require an extensive pre-treatment or activation period to establish full catalytic activity. This is typically 72 hours for conventionally prepared catalyst.

**NANOCRystALLINE CERIUM OXIDE (CeO$_2$)**

Nanocrystalline CeO$_2$ was prepared by precipitation of a solution of the acetate using supercritical CeO$_2$ as an anti-solvent. It was demonstrated that gold supported on this material is very active for the oxidation of CO at ambient temperature, particularly in comparison with CeO$_2$ prepared in a conventional manner by thermal decomposition of the acetate. Catalytic activity was found to be ~25 times greater than previous Au/CeO$_2$ catalysts, due to better dispersion of gold particles.

**Most active catalyst has Au well dispersed**

**Less active catalyst has distinct Au nanocrystals**

A key target for the Cardiff Group is to develop a non-nitrate route for the copper/zinc oxide/alumina methanol catalyst. This is currently prepared by conventional precipitation of soluble nitrate salts with sodium carbonate to yield an insoluble carbonate. It is anticipated that the supercritical CO$_2$ process will circumvent the need for nitrate salts.

Preparation and use of nitrates contribute greatly to environmental burden and nitrous oxide, a by-product of nitric acid manufacture is >150 times more potent as a greenhouse gas than carbon dioxide. The non-nitrate route is currently the topic of an industrial collaboration with Johnson Matthey Catalysts.

In recognition of their work on more sustainable routes to catalyst manufacture, the research team at Cardiff University were awarded the Envirowise Green Chemistry Award by the IChemE.