

FINAL ANALYSIS

Catalysis “After the Goldrush”

Cardiff University, UK, has recently been awarded European Union (EU) funding for a new programme entitled “After the Goldrush” (1). This programme aims to explore the implications of discoveries made over the last 25 years of intensive research into catalysis by gold and so accelerate the discovery and development of other catalytic materials such as those based on platinum group metals (pgms), which may hold the key to solving many of the pressing challenges facing us now and in the future.

Gold and the Platinum Group Metals

The independent discoveries that gold can catalyse the hydrochlorination of acetylene (2) and that it shows good activity in the oxidation of carbon monoxide (3) marked the beginning of the current era of interest in nanoparticle gold catalysis. What followed over the next few decades can be seen as a global and highly productive screening exercise, which has generated a long list of potential applications. Among the most promising end-uses for gold are carbon monoxide clean-up either by preferential oxidation (4) or by water gas shift (5), selective hydrogenation (6) and dehydrogenation (7) of hydrocarbons and oxygenates, and oxygen insertion through formation of a peroxide intermediate (8). For several of these reactions, gold has impressive catalytic activity (2–5).

Just one gold-containing catalyst has so far made it into the marketplace, and it is notable that palladium is a key constituent: supported gold-palladium has become established as the catalyst of choice in the now dominant fluidised-bed process for producing vinyl acetate monomer (9). This apparently slow uptake by industry needs to be seen in the context of the 10–15 year development time required for many catalytic processes, which may well mean that there are more gold or gold-pgm catalysts in the pipeline. However, it is also clear that there are specific obstacles on the route to commercialising any new catalytic technology that relies on gold. Some of these, such as the high cost of the metal per troy ounce, are beyond the control of the research community, but

others, such as poor durability of the catalysts or the irreproducibility of the preparative methods, can only be solved in the laboratory.

Fundamental Understanding

It is too soon to put a value on the commercial impact of gold catalysts, but the progress made in understanding catalysis on the nanoscale cannot be understated and will have broad implications for other metals including pgms. The study of gold catalysis has revealed to us the key interdependence between the size of a metal particle, its morphology and the extent of its interaction with the support material (10). It has made us push existing characterisation techniques to new limits (11), develop new methods for probing the active site (12), and ask fundamental questions about why the surface reactivity of near-neighbours in the Periodic Table can vary so much (13). It may even be leading us towards more active, selective and durable catalyst formulations in which gold might be an essential but subsidiary component alongside other metals (14). A representative study of gold and gold-palladium nanoparticles is shown in **Figure 1** (15).

With hindsight we can now appreciate how the publication of the seminal papers on gold catalysis (2,3) coincided with tetrachloroauric acid becoming commercially available, making the preparation of supported gold catalysts much simpler and, in turn, opening the floodgates onto a largely untouched area of scientific study. Although it is often asked whether the study of other catalytic materials has suffered as a consequence, the publication rates for the pgms suggest otherwise (**Figure 2**). Rather than dwell on this question, however, it is probably more productive to consider how much of the emergent learning from the work on gold is either generic or transferable to other areas of catalysis. It is exactly this approach that the Cardiff Catalysis Institute will be taking in its programme “After the Goldrush”.

Over a relatively short time span, gold catalysis has become a dynamic and highly creative field. The

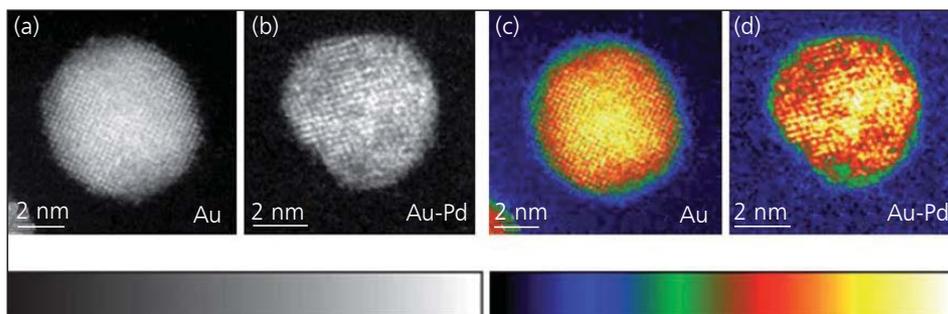


Fig. 1. Scanning transmission electron microscopy-high angle annular dark-field imaging (STEM-HAADF) images of metallic nanoparticles: (a) and (c): pure gold; (b) and (d): bimetallic gold-palladium nanoparticles with high selective oxidation activity. (Regions within the nanoparticle with a higher local concentration of gold appear brighter than the palladium-rich areas by virtue of the higher atomic number of gold.) (Reproduced by permission of The Royal Society of Chemistry (15))

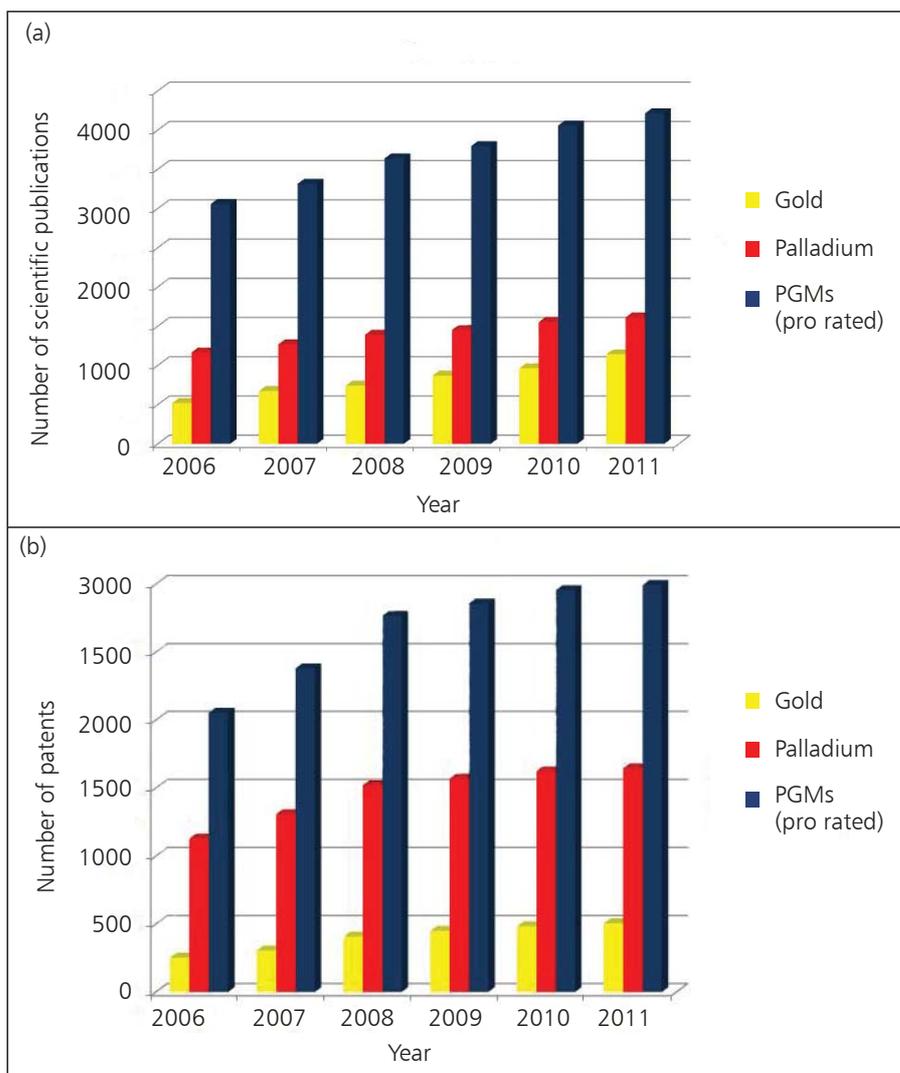


Fig. 2. Publications featuring gold, palladium or pgms with the role 'catalyst use' in: (a) scientific literature, taken from the Chemical Abstracts database; (b) patent literature, for which the numbers refer to the year of publication of the basic patent excluding subsequent family members. The numbers for pgms are pro rated (i.e. calculated from the exact breakdown for palladium)

programme “After the Goldrush” will take the learning so far gained and use it to build on the already substantial knowledge base that exists in the parallel field of precious metal catalysis. It is a simple rationale. By adding new impetus to the study of the classic catalytic metals such as platinum, palladium, rhodium and ruthenium, we will greatly increase our chances of developing breakthrough technologies, which we need in order to address the pressing global challenges that we face. These include upgrading waste, the sustainable synthesis of chemical intermediates and products, and the decarbonisation of transport.

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