WORLD GOLD COUNCIL

Gold
The hidden element in innovation

About the World Gold Council

The World Gold Council (WGC) is the market development organisation for the gold industry. Working within the investment, jewellery and technology sectors, as well as engaging in government affairs, its purpose is to provide industry leadership, whilst stimulating and sustaining demand for gold.

We develop gold-backed solutions, services and markets, based on true market insight. As a result, we create structural shifts in demand for gold across key market sectors.

We provide insights into the international gold markets, helping people to better understand the wealth preservation qualities of gold and its role in meeting the social and environmental needs of society.

Based in the UK, with operations in India, the Far East, the Middle East, Europe and the USA, the WGC is an association whose members include the world's leading and most forward thinking gold mining companies.

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Executive summary

Gold's applications are all around us. Highly conductive and corrosion resistant, the metal is an essential component in everyday electronic devices. In addition, the use of gold in medicine and chemistry is critical to a range of other well-known products and processes too. In many ways gold is the 'hidden element'; quietly playing a vital role in the functioning of things we take for granted.

Recent years have seen the emergence of many more exciting potential applications for gold. The World Gold Council supports the development of these innovations, giving them the best chance of evolving into successful commercial applications which will ultimately benefit society. We are playing a pivotal role in the transition from 'lab' to 'market' by investing in a range of technology development activities in the fields of medical applications, environmental control and renewable energy. From cancer detection to cleaner water and improved automobile emission control, gold is set to play a key role in a safer, healthier, more environmentally-friendly future.

As an example, the World Gold Council is actively supporting the expanding applications for gold nanoparticles in important medical diagnostics, a market predicted to almost double by 2015. Gold nanoparticles are showing great promise in the diagnosis of a range of illnesses and diseases including cancer, HIV/AIDS and Alzheimer's. Similarly, it has been demonstrated that gold nanoparticles loaded with antibiotics show significant antimicrobial activity. During 2011, World Gold Council support will enable further optimisation of the gold-based materials involved in each of these technologies.

The production of almost all commercially-important substances and chemicals involves the use of a catalyst to improve the efficiency and economics of the process. Selecting the correct catalyst is critical to many processes; from pharmaceutical production to controlling automotive emissions. With long undiscovered, unique performance characteristics, gold is now considered to be a viable, cost-effective catalyst for a range of processes. Seeing this potential, the World Gold Council has invested to accelerate the commercial use of gold in automotive emissions control. This technology is entering production during the first quarter of 2011. World Gold Council-supported researchers are also using gold catalysts and nanoparticles to clean up contaminated water supplies, reduce mercury emissions and produce common chemicals more efficiently. These technologies are also well on the way to commercial use.

By continuously reviewing and monitoring the global research landscape for new breakthroughs in gold-related science and technology, the World Gold Council will be able to identify and accelerate the development of other innovations. Whether it is more efficient solar cells, next generation rechargeable batteries or new medical uses, we continue to help put gold at the heart of technology.

An enduring track record

Gold has a long and fascinating history in technology. It is the material of choice in a diverse range of applications and in many cases, its unique properties make it the only choice for guaranteed reliability and functionality.

7th century BC
The first gold dentistry

4th century AD
The first gold nanoparticles

1803
The first gold electroplating

1909
Gold and the structure of the atom

1957
Gold bonded microchips

Key moments in history

7th century BC The first gold dentistry
The Etruscans used gold wire to hold substitute teeth in place, which is the first recorded use of gold in dentistry. The advantages of gold alloys for dental applications, its biocompatibility, malleability and resistance to corrosion, mean it is still used extensively today.

4th century AD The first gold nanoparticles
The Romans used gold to colour glassware such as the Lycurgus Cup. The glass contains nanoparticles of metals, including gold, that reflect light in a unique way.

1803 The first gold electroplating
The first recorded electroplating experiment was carried out by Professor Luigi Brugnatelli at the University of Pavia. Plating gold for electrical contacts is now a key technology used by the electronics industry in modern mobile phones and computers.

1909 Gold and the structure of the atom
Nobel Prize winner Ernest Rutherford used gold foil in an experiment to successfully unravel the structure of the atom.

1957 Gold bonded microchips
Gold bonding wire is used in microchips built at the Bell Laboratories in the US. Nowadays literally billions of wires are bonded in this manner annually for use in the consumer electronic devices we all take for granted.

1961
Gold into space

1980s
Gold as a catalyst

1985
Treating arthritis

1990s
Pregnancy testing kits

2001
Medical implants

2011
Catalytic converters

1961 Gold into space
The first manned space flight used gold to protect sensitive instruments from radiation. By 1980, the US space shuttle contained nearly 41kg of gold used in brazing alloys, fuel cell fabrication, for coated plastic films or in electrical contacts.

1980s Gold as a catalyst
Professor Graham Hutchings in South Africa and Professor Masatake Haruta from Japan published research showing how gold can be a catalyst for chemical reactions. Catalysts are an essential component of many different industrial processes used to produce chemicals, foodstuffs and other materials we take for granted.

1985 Treating arthritis
Auranofin, a gold-based drug developed by pharmaceutical giant SmithKline & French for the treatment of rheumatoid arthritis, received regulatory approval and went on sale for the first time. Gold is still used to treat this condition today.

1990s Pregnancy testing kits
Gold nanoparticles were at the core of the FDA-cleared First Response pregnancy testing kits. Initially marketed by Carter-Wallace, these tests are still available today through consumer healthcare giant Church and Dwight.

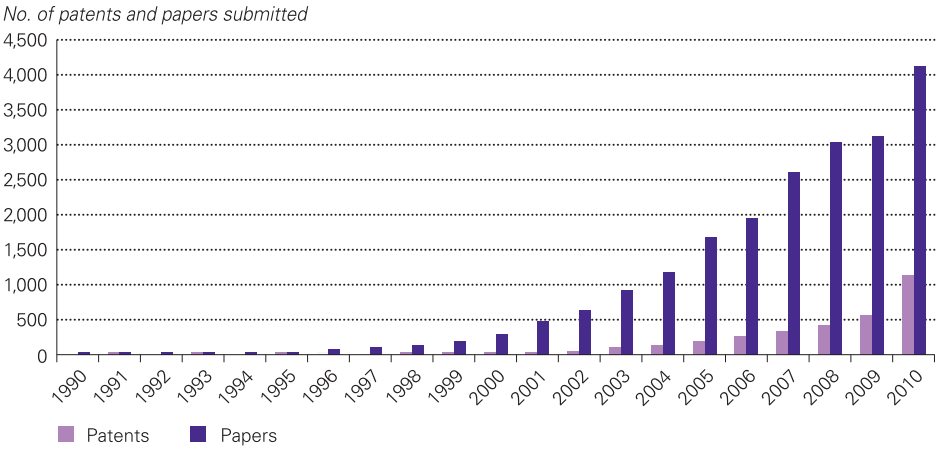
2001 Medical implants
Boston Scientific market the *Niroyal*™ stent – the first gold-plated stent. Stents act like scaffolding, propping up the blood vessels and keeping them open to allow adequate blood flow. The radiopacity of gold means that gold-plated stents offer the best visibility under an x-ray enabling them to be positioned where the surgeon wants them.

2011 Catalytic convertors
With World Gold Council support, US company Nanostellar commercialised the first automotive catalytic convertor technology that uses gold alongside other precious metals, like platinum, for more effective control of car emissions.

Gold's technological applications are all around us, in many different forms. Examine your mobile phone and you will almost certainly see gold plated contacts. Inside your computer and on your digital camera memory card you will find gold plating on the circuit boards. As a result of the growth in consumer electronics, the long term annual consumption of gold in this market is increasing. Where reliability requirements are high, gold is the preferred choice. Engineers specify gold in a number of other high-tech applications, such as in fuel cells, jet engines, as a lubricating material and as a coating on architectural glass, to name just a few. Gold and medicine have also been linked for millennia. More recent years have seen dentistry, precise surgery, rapid and robust diagnostics and therapeutics all benefit from gold's inherent versatility and biocompatibility.

As technology continues to advance, gold will be used in a multitude of new products and processes and we expect innovations from new research to develop into significant new markets. Recent years have seen an explosion of interest in the use of gold in science and technology, mainly as a result of the emergence of nanotechnology. Analysis of scientific research papers and published patent applications reveals exceptional growth in this field (see chart below). Conversion of just a fraction of this promising research into commercial applications will open exciting new markets for gold.

Published patents and research papers on the use of gold in nanoscience and technology



Source: World Gold Council

Thousands of copies of the recent World Gold Council white paper *Gold for Good – Gold and Nanotechnology in the Age of Innovation*[1] have been requested since its launch early in 2010. The popularity of this report, and the subsequent coverage it received in publications such as *Nature Nanotechnology*,[2] suggest that many others share the World Gold Council's excitement about the potential of these technologies.

Despite this potential, there is a gap between government-funded early stage research and venture capital-backed technology commercialisation. This means promising research and technology can often struggle to reach the market. The World Gold Council helps bridge this gap through supporting the development of exciting gold-based technologies, so that many of them will ultimately evolve into successful commercial applications which benefit society in the longer-term.

The World Gold Council is playing a pivotal role in the transition from 'lab' to 'market' by investing in technology development in the following areas.

- medical diagnosis and treatment
- environmental monitoring and control
- energy efficiency and renewables

Working with some of the world's leading researchers, we are helping to drive gold-based innovations towards commercialisation. This report explores a few examples of the World Gold Council's involvement in supporting cutting-edge technologies.

Our advisory board

To provide additional insight and expert guidance on our research and development activities in 2011 and beyond, the World Gold Council has formed a new International Technology Advisory Board. The board is comprised of internationally recognised experts in relevant fields.
Current members are:

Professor Enrique Iglesia
Theodore Vermeulen Chair in Chemical Engineering, University of California at Berkeley, USA

Dr Barry Murrer
Director of Technology Centre, Johnson Matthey Plc, UK

Professor T. Pradeep
Indian Institute of Technology Madras, India

Professor Vincent Rotello
Charles A. Goessmann Professor of Chemistry, University of Massachusetts, USA

Cutting-edge diagnostics

Most people are unaware that gold has long been at the heart of one of the most common diagnostic tools used by millions of people every year; pregnancy testing kits. Small gold nanoparticles are the perfect material for this quick, reliable diagnostic test.

The small quantities of gold required in most diagnostic devices make it a cost effective use of the metal, whilst the nanoparticle stability, sensitivity and reproducibility of manufacture help guarantee test accuracy. Other established examples of similar diagnostic tools include the simple tests sold by Merck KGaA to detect rapidly the range of pathogens such as Salmonella, *E. Coli* and Campylobacter in food.

According to a recent BCC research report,[3] in 2010, the global value of gold nanoparticle based diagnostics was $50 million, a figure projected to almost double by 2015 predominantly as a result of exciting advances in the field. One such example is the ongoing growth of the Illinois-based company, Nanosphere, which has delivered a fully integrated diagnostics platform called *Verigene™* to market. The *Verigene™* system operates by detecting specific biomolecule targets with gold nanoparticles. These gold-based probes are non-toxic, have a long shelf life and, most importantly, are extraordinarily sensitive. The system can be used to diagnose a broad range of conditions, a number of which have now received FDA approval in the US. Additionally, Nanosphere has a collaboration with Eli Lilly, one of the world's leading healthcare companies, which utilises its gold-based technologies in the field of early drug discovery.

According to a recent report,[3] the global value of gold nanoparticle-based diagnostics is projected to almost double by 2015.

The World Gold Council is actively supporting the expansion of markets for gold nanoparticles in diagnostics. One such example is the groundbreaking work currently being carried out by Professor Molly Stevens at Imperial College, London. Professor Stevens and her team are exploiting the versatility of the gold nanoparticle by coating the surface of the tiny metal particles with a range of large biological molecules which effectively create a 'mesh'. The system is designed so that if this mesh is exposed to certain enzymes indicative of specific disease states, it will dissipate and change colour.[4] This simple, elegant tool is showing great promise in the diagnosis of a range of diseases including HIV/AIDS and sepsis.

A second World Gold Council-supported project in the field of diagnostics involves the development of equipment which accurately detects proteins linked to cancer. This research is led by US-based researchers Professor Qun Huo of the University of Central Florida and Dr Cheryl Baker of M.D. Anderson-Orlando's Cancer Research Institute. The technology hinges on engineering gold nanoparticles to attach themselves to specific cancer-related proteins. When these proteins are present in the blood, they sense the gold nanoparticles and form 'clusters' in the solution. It is these clusters that can be measured using a technique called Dynamic Light Scattering, an extremely sensitive particle sizing method.[5] If clusters are shown to be present, the patient can be referred to a doctor for further testing and treatment if necessary. This exciting research has now been spun out into a start up company called Nanodiscovery Inc., which has already developed a prototype instrument and is aiming to begin supplying the technology to research centres in 2011.

New antimicrobial materials

The prevention and treatment of infection has long been one of medicine's biggest challenges, and is a challenge that continues to this day. Novel materials are constantly being sought to help tackle the serious issue of antimicrobial resistance.

Silver has a long history of being used as an antimicrobial agent, and is applied in a large number of marketed products. Probably the best known of these is the use of nano-silver impregnated dressings to treat wounds and prevent infections. However, the antimicrobial effectiveness of silver is known to deplete over time. Tackling this drawback has long challenged researchers, but recent World Gold Council-supported research has demonstrated that combining gold with the silver can lead to improved and longer-lasting antimicrobial effectiveness.[6]

Another recent development by researchers in the UK has demonstrated that gold nanoparticles loaded with Cefaclor, a second-generation antibiotic, show extremely promising antimicrobial activity when formulated into a thin film.[7] Manufacturing the particles is straightforward and the formulated film is robust. It appears to increase significantly the longevity of the antibacterial activity against a range of bacteria including *E. coli* and *S. aureus*.

Combining gold with the silver can lead to improved and longer-lasting antimicrobial effectiveness.

World Gold Council support of this work in 2011 will allow optimisation of both the materials and processes involved in this exciting breakthrough.

Cleaner chemical production

The production of almost all commercially-important substances and chemicals involves the use of a catalyst to improve the efficiency and economics of the process. Selecting the correct catalyst is critical to many processes ranging from pharmaceutical manufacturing to oil refining.

Size is important in catalysis. Chemical reactions almost always take place on the surface of the catalyst so the use of small particles is an effective way of increasing surface area. Using precious metal nanoparticles can reduce the amount of metal required, and optimised catalysts can both lower the temperatures and pressures required in some industrial processes, improving the efficiency of reactions. This can result in more of the desired chemical being produced, and less waste.

For many years, gold was believed to be of no practical use as a catalyst, despite other precious metals like platinum and silver being widely employed. This has now changed, with gold a viable catalyst in a variety of industrially important processes, including in Vinyl Acetate Monomer (VAM) production. VAM is a key ingredient in emulsion polymers, resins and intermediates used in paints and adhesives. A related and even more widely used 'building block' chemical is Vinyl Chloride Monomer (VCM), the manufacture of which relies on a polluting, mercury-based catalyst. China alone used approximately 800 tons of mercury for VCM production in 2005, and this is widely believed to be to be the single largest use of mercury in any one sector in any country on earth.[8]

Gold-based catalysts form the basis of a far more desirable and efficient method for manufacturing VCM, which completely removes the need for a mercury catalyst. Professor Graham Hutchings at Cardiff University, one of the leading pioneers of gold catalysis, has studied this particular reaction in great depth[9] and in collaboration with Johnson Matthey and the World Gold Council, has recently identified improved methods and materials for implementing gold into this important manufacturing process. A new cost-effective use for gold in cleaner chemical production is on the horizon.

Reducing automotive emissions

The World Gold Council has a market changing partnership with Silicon Valley-based Nanostellar, which is pioneering the use of gold in automotive emission control.

Proclaimed as a 2008 'Technology Pioneer' by the World Economic Forum, Nanostellar has developed a new catalyst product, *NS Gold™*, for use in the automotive industry which, for the first time, includes gold alongside traditional platinum and palladium metals.
Auto catalysts have historically used platinum group metals to control harmful elements in automotive exhaust fumes; carbon monoxide (a poisonous gas), hydrocarbons (from partially burned fuel that gives off diesel or petrol odour), particulate matter (or smoke – which contains cancer causing compounds) and NOx (smog forming compounds). The inclusion of gold enables manufacturers of light and heavy-duty diesel engines to reduce these emissions at lower cost, enabling significant savings for automotive manufacturers.

The World Gold Council invested in Nanostellar to accelerate the commercialisation of the technology, putting gold at the heart of automotive emissions control. The technology is entering production in the first quarter of 2011.

World Gold Council has helped to place gold at the heart of future technologies like automotive emissions control.

Improving water quality and health

World Gold Council's support for new technologies has extended to India, the largest market in the world for gold.

For Professor T. Pradeep, at the Indian Institute of Technology in Madras, gold's central position in Indian society could soon extend from jewellery into new technology. Professor Pradeep, a leading expert in water purification technology and nanomaterials, and recent recipient of the prestigious Shanti Swarup Bhatnagar Prize, has shown gold nanoparticles can detect and remove pesticides, halogenated organics and heavy metals from drinking water.[10]

Through the support of the World Gold Council the range of contaminants that can be addressed by gold nanoparticles has been extended and the technology moved closer towards commercialisation. With thousands of people in India at risk of suffering health effects as a consequence of drinking contaminated water, the contribution that this gold technology could make to this part of the world is very exciting and potentially life-changing.

On the other side of the world another leading researcher is using an equally innovative approach to clean up water supplies. Professor Michael Wong at Rice University in Houston has developed a novel gold-palladium nanoparticle catalyst, which shows incredibly high activity in breaking up a common chlorinated pollutant into harmless constituents.[11]

The chemical, trichloroethylene, is known to be a poisonous groundwater pollutant. It is linked to a variety of serious human health issues including liver damage, impaired pregnancy and cancer, making its removal from all water supplies critical. To accelerate the commercialisation of this promising technology, the World Gold Council supported a collaborative partnership alongside catalyst developers Mintek in South Africa (under Project AuTEK) and the research team at Rice University. Through this partnership a gold-based catalyst has been designed, manufactured and tested under laboratory conditions. Early results are impressive, with significant efficiency gains achieved over existing technology. A pilot facility is currently under construction at a major chemical company site within the US, where the effectiveness of the gold catalyst will be further tested at scale during 2011.

World Gold Council supported a collaborative partnership alongside catalyst developers Mintek in South Africa (under Project AuTEK) and the research team in Rice University.

Environmental protection

Reducing emissions of harmful pollutants is a key target of practically every government on earth. One example of such a pollutant is mercury, which is found naturally in small deposits around the world. However, it is also a by-product of coal-fired boilers which can release small quantities of the metal into the atmosphere.

As mercury has been linked to Alzheimer's disease and autism, it is anticipated that the US Environmental Protection Agency (EPA) is soon to impose stringent limits on mercury emissions from a range of boilers in the utilities industry.[12] Couple this with the fact that the US is relying increasingly on the use of coal to produce electrical power, it is clear that any such limits could prove difficult (and costly) to meet. Consequently, there is currently a major focus on identifying methods to more effectively prevent the release of toxic forms of mercury into the atmosphere.

Published research confirms that gold-based catalysts can provide a solution. Studies performed at the US National Energy Technology Laboratory (NETL) have shown gold nanoparticles to have considerable promise as mercury oxidation catalysts, capable of substantially reducing emissions. Full-scale trials are now underway in one US power station. In parallel, further improvements in gold catalyst formulations are being supported by the World Gold Council at Queen's University, Belfast.[13]

Clean energy

Reducing the world's reliance on burning fossil fuels as a source of energy is critical to both reducing pollution and tackling climate change.

Achieving this relies on successfully identifying new technologies which can exploit clean, renewable sources of energy. This represents a significant challenge, but it is an area in which gold is showing considerable promise. Recently, a catalyst was developed by researchers at MIT that has the potential to make rechargeable lithium-air batteries significantly more efficient, a step toward making these high-energy-density batteries practical for use in electric vehicles and elsewhere. With senior automobile industry figures suggesting that electric cars will comprise 10% of the market by 2020, this is clearly a field of critical importance.[14] The catalyst developed at MIT consists of nanoparticles of gold and platinum and the research suggests that this new approach to lithium-air battery catalysts could lead to the even higher efficiencies needed for commercial batteries.[15]

A related area of interest is that of fuel cells which have long been promoted as a leading technology in future renewable energy sources. For commercial applications, separator plates (a key component in many fuel cells) must be resistant to corrosion, be durable and have low electrical resistance. The US Department of Energy (DOE) has set targets in these areas that fuel cell manufacturers should achieve.[16] World Gold Council has begun championing the use of gold-coated stainless steel as a durable, cost-effective solution to the targets set by the DOE. Ford Motor Company is particularly interested in this technology, with a recent report detailing the development of cost-effective, nanoscale gold coatings for use in their fuel cell programme.[17]

Finally, whilst the solar cell market is now relatively well established, there are still key technical issues to be tackled. These stem from the relatively poor efficiencies of commercially available cells, making any improvements in this field particularly desirable. Early research has shown gold nanomaterials may be used as an efficiency-improving additive for a range of solar cell designs; the gold nanoparticles enhance the optical absorption in the range of visible light, potentially giving rise to improved conversion of solar energy.

The World Gold Council is currently in discussion with a number of prominent academic groups and start up companies in the clean energy space. Researchers working in the field are encouraged to contact us to explore any opportunities for collaboration.

Accelerating developments

The World Gold Council creates value by accelerating the emergence of new gold-based technologies. By continuously reviewing and monitoring the global research landscape for breakthroughs and emerging technologies we are able to progress with key market developments.

Our expertise is utilised by an extensive network of stakeholders including industrial manufacturers, investors, researchers and academics. Where appropriate we make direct investments in promising innovations to help overcome barriers on the road to commercialisation.

We are interested in working with researchers and companies developing gold-based innovations, and would encourage relevant parties to contact technology@gold.org or visit our website at www.gold.org/technology for more information.

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