MINTEK PROVIDES WORLD-CLASS R&D EXPERTISE, TESTWORK, AND PROCESS OPTIMISATION for the precious and base metals, ferro-alloy, industrial mineral and uranium sectors on an international basis. The activities range from initial bench-top investigations to full process flowsheet development and the design, construction, commissioning, and optimisation of industrial plants.

Mintek is strongly committed to delivering high-quality results within strict constraints of budget and time-frame. To this end, our engineers, scientists and technicians work in close liaison with clients and their engineering contractors, who are encouraged to actively participate in project planning and testwork. This interaction enables clients to discuss issues as development work moves forward, and increases Mintek’s own capabilities by drawing attention to areas that require focused and applied R&D. The new knowledge is then fed back into client-oriented services.

Mintek also undertakes medium- and long-term strategic applied R&D, which is aimed at building the organisation’s science and technological base and developing new technologies and products that will convey benefits industry-wide. This activity is funded mainly by the State Science Vote (Parliamentary Grant) to Mintek as a Science Council, and also through supplementary sources such as bilateral agreements and other funding and donor agencies. Most of the projects in this category are undertaken as joint ventures or in collaboration with other research institutions, including local and overseas universities, professional bodies, and industry partners.

1. Production of nanomaterials by electrospinning.
2. Flotation testwork on a PGM ore.
3. Tapping Mintek’s ConRoast DC arc furnace.
4. Bioleaching columns.
AuTEK – developing new industrial applications for gold

PROJECT AUTEK, THE COLLABORATIVE R&D INITIATIVE BETWEEN MINTEK AND SOUTH AFRICA’S THREE MAJOR GOLD PRODUCERS, is now in its tenth year. The project has three main focus areas, namely, catalysis, nanotechnology, and biomedical applications. In addition to the sponsorship provided by its industrial partners, Project AuTEK has been awarded THRIP funding for a third consecutive year, which has enabled the acquisition of cutting-edge equipment to further enhance in-house capabilities.

Biomedical programme

The HIV programme forms the primary focus of the AuTEK Biomed programme, jointly funded by Harmony Gold Mining Company Limited and Mintek. The programme conducts in-depth research into the design and discovery of novel gold-based compounds that inhibit HIV replication. Research at Mintek, supported through collaborations with various university groups, focuses on developing new assays, elucidating the mechanism of action of gold-based compounds, rational design of novel inhibitors for specific HIV targets, and screening compounds for potential activity.

Assay development is undertaken so that novel compounds can be biologically evaluated for anti-HIV activity. AuTEK Biomed has

2. Gold and silver granules produced by the Minataur™ hydrometallurgical refining process.
optimised and validated an assay to identify inhibitors of HIV-1 integrase. HIV-1 integrase, an enzyme fundamental for HIV-1 replication, is studied extensively internationally, but has featured in South African research activities only recently. As the only local research group to have expressed and isolated HIV-1 integrase, AuTEK Biomed is in a prime position to supply reagents and products to facilitate the research. Mintek plans to make HIV-1 integrase and an integrase assay kit available at an affordable cost to local researchers, and is investigating supplying the same to international users. Two further assays have been developed and are currently being used to obtain information that is critical in the drug discovery and development process.

Elucidation of the mechanism by which gold-based synthetic compounds inhibit HIV-1 replication will allow for the rational design of gold-based compounds and ensure focused, target-based research. Great progress has been made in this regard and it is expected that the full mechanism of action will be derived by mid-2010.

Screening has been conducted on a continuous basis, and a further three gold-based compounds were identified as showing anti-HIV activity.

Similar to the HIV programme, the primary objective of the cancer programme is to identify promising inhibitors of cancer for further development. During the period under review, university-based research groups continued investigations into the synthesis of novel compounds and subsequent evaluation, and 26 compounds were submitted to international partners for preliminary screening. Two compounds previously submitted to the National Cancer Institute (NCI) progressed to in vivo hollow fibre assays, which reflects an advanced stage of preclinical development and the results from one of these compounds were sufficiently encouraging to warrant further development.

Most of the research activities under the malaria programme take place at the University of Cape Town (UCT), with Mintek acting as the link to development of promising results. Malaria screening was conducted at three institutes: the Department of Medicine, Division of Pharmacology at UCT, the London School of Hygiene and Tropical Medicine (LSHTM), and the Department of Medicine, San Francisco General Hospital, and the University of California at

1. Gold nanoparticles of different morphologies produced by using proteins as a biological template.
2. Optical sorting of a gold ore.
3. The new Matrix Cynoprobe for on-line measurement of cyanide in environmental aquatic samples.
4. The advanced gold leach facility.
AuTEK offers three “standard” catalysts: 1wt% gold mounted on catalysts in many different applications. In terms of products, AuTEK is also involved in developing catalytic materials for the oxidation of various hydrocarbons using molecular oxygen. This is in contrast to current enzymatic methods or methods that involve stoichiometric oxygen donors, which result in environmentally harmful by-products or poor activity/selectivity.

Product development work is continuing in-house, and in some cases in conjunction with SME partners. A major area of investigation is respiratory protection (gas masks), and integration of AuTEK’s AUROlité CO oxidation catalysts in these systems continues. AuTEK is also involved in developing catalytic materials that show enhanced resistance to deactivation, for long term CO oxidation applications such as air purification, fire protection, and mine refuge stations.

Another area where catalysis work has continued is in the Precious Metals Development Network (PMDN) of the DST’s Advanced Metals Initiative (AMI). In this programme Mintek is now focused on the development of a new class of gold and gold-palladium based catalysts for the epoxidation of propene to propene oxide, which is a very valuable intermediate chemical feedstock. The work is carried out in a three-way collaboration with Sasol and Cardiff University, and the past year has seen the secondment of one Mintek researcher to Cardiff University for a one-year post-doctoral fellowship sponsored by Sasol. Valuable results were obtained that have opened a new direction in the epoxidation process, and each of the partners will now investigate different aspects of the way forward.

Nanoscience and technology programme

The primary objectives under the nanoscience and nanotechnology programme are the development of nanostructured materials and nanomaterials and their applications in health (therapeutics and diagnostics) and water (monitoring and remediation) sectors. The activities focus on a number of issues including the development of research platforms, encouraging and promoting the formation of collaborative...
networks, addressing human capital development and bridging the “innovation chasm” by translating the research outputs into products and technology. All these activities are co-ordinated within the two major programmes in Mintek’s Advanced Materials Division (AMD) - Project AuTEK (GoldFields/Mintek) and the DST/Mintek Nanotechnology Innovation Centre (NIC).

While Project AuTEK focuses on the development of gold nanotechnology, the NIC focuses on the broader area of nanotechnology application in health and water. Through the NIC, formal collaborative networks have been established with three Universities. The University of the Western Cape and Rhodes undertake and co-ordinate research activities in health (therapeutics and diagnostics), while the University of Johannesburg is involved in the field of water (monitoring and remediation). Mintek, the hub of the NIC, hosts the nanomaterials platform and all the development activities of the NIC. The Water Research Commission (WRC) and the Medical Research Council (MRC) form an integral part of the NIC and provide advice to the research and development thrusts to address relevant South African priority areas in water and health respectively. Good progress has been made during the first funding cycle (2007 - 2010: Phase I) of the NIC. A total of 93 post-graduate students (14 Honours, 35 M.Sc., 30 Ph.D. and 14 Post-doctoral) were involved at the NIC Research Units. About 90 per cent of these are previously disadvantaged individuals, and 52 per cent are female students. Various commercial products have been developed, such as nanomaterials or - particles, bioconjugates, and point-of-care (POC) prototype diagnostic devices. A total of 216 contributions were made to the international nanoscience community in the form of 125 journal publications and 91 conference papers/posters.

Systems of biomolecules conjugated onto gold nanoparticles of various sizes have been prepared and are extensively used in the optical diagnostic programme, which focuses on the development of lateral flow POC tests for early detection of human and animal diseases of importance in South Africa. Tests for TB, malaria and brucellosis (the latter in conjunction with the Onderstepoort Veterinary Institute (OVI) have been developed to proof-of-concept stage. One of the current highlights for the Unit was the successful attachment of the Rift Valley Fever (RVF) antibody to gold nanoparticles. Work on the magnetic core-shell Fe₃O₄-Au nanoparticles complements the gold-based systems in the optical diagnostic platform. A long-term study on the effect of various storage regimes on the stability of both the conjugates and POC kits was started recently and will form part of the validation processes.

Some of the projects emanating from the Biolabels platform are undertaken at the University of Pretoria, in which synthetic drugs are attached to gold nanoparticles. These nanoparticle systems are assessed for their effects on cancerous tumours in vivo studies. A project on the use of gold conjugates to inhibit the growth of new blood vessels in adipose tissue (fat tissue) is under way in collaboration with the MRC.

The electrochemistry programme focuses on the development of sensors for the early detection and monitoring of diseases in animals and humans, as well as water-born pollutants. Electrochemical sensors, in contrast to the optical devices, are important in that they yield both quantitative and qualitative results.

Mintek and the node at the University of Johannesburg are developing nanostructured membranes and composites to address micro-pollutants in water. This research is targeted specifically at those pollutants and viruses that current technology is unable to remove. The work has led to collaborations with the University of California, Los Angeles, (UCLA) and the University of Ben Gurion of the Negev, where collaborative work is been undertaken by researchers from both Mintek and the University of Johannesburg.

The synthesis of gold nanoparticles and nanoplates using proteins as a biological template has been successfully demonstrated on laboratory-scale at Mintek. A variety of morphologies such as triangles and hexagons can be reproducibly synthesised. Current efforts are focused on separating the particles according to size and shape and demonstrating larger-scale synthesis of the particles before investigating potential applications.

The construction of a R13-million advanced cleanroom facility (ISO 3), supported by the Department of Science and Technology, is scheduled for completion in December 2010. The facility will enable Mintek to develop and fabricate systems and products under current Good Manufacturing Processes, and also to meet the required Good Laboratory Practice (GLP) and (ISO) standards for medical devices.

Gold process testwork

A large number of investigations into oxygen demand and its effect on the cyanidation process were conducted on gold-bearing sulphide ores for Maelgwyn Mineral Services Africa.

Cyanide diagnostic leach tests were conducted on various gold-bearing materials from a number of gold processing plants, including:

- Blyvooruitzicht and Benoni tailings (DRD Gold Ltd);
- Kwekwe Mine roasted tailings dump material (Minerals Marketing Corporation of Zimbabwe - MMCZ);
- ChemWes flotation tailings (First Uranium);
- Elandsrand Gold Plant residue (Harmony Gold Mining Company Limited); and,
- New Kleinfontein Gold Plant feed material (Gold One International).

Process optimisation investigations were carried out on plant feed and residues from Gold Fields’ Driefontein and South Deep gold plants, and cyanidation amenability testwork was also conducted on copper-bearing tailings from Tsumeb in Namibia.

Screening, comminution and cyanidation testwork was carried out on a bulk sample of “free dig” surface material from Shanta Gold Limited’s Chunya project in Tanzania.
A new-generation Mikrosort® secondary optical sorter from Commodas, capable of throughputs of up to 100 tons per hour at a feed size range of 20 to 80 millimetres (depending on the mineral composition) was commissioned at Mintek. A key feature of the new facility is its ability to recycle the products back to the feed, so that throughput tests can be conducted to specify the performance under various loading conditions. The sorter has been tested extensively on gold ores, particularly waste rock dumps as well as on underground ore, with efficient, cost-effective results demonstrated. As a result of the merger between Commodas and Ultrasort, a diamond sorter, has also been commissioned on site at Mintek.

Research and Development

Mintek has commissioned a new advanced gold leach facility aimed at optimising the design and operation of gold recovery circuits from both the environmental and economic standpoints. The fully instrumented mini-plant is designed to supplement the widely-used bottle roll technique for gold amenability testwork by allowing the leaching kinetics of the target metal and the environmental parameters to be monitored in relation to the process conditions. The environmentally harmful elements such as cyanide, arsenic, and heavy metals are tracked in “real time” as the leach progresses. Understanding how the chemistry of the process changes in response to variations in the controllable leach parameters will enable Mintek to improve leach plant designs to meet environmental protection standards without compromising gold recovery.

It is known that many of the novel processing techniques such as high pressure grinding rolls, ultra-fine milling, and high shear oxidative leaching have positive impacts with regards to gold recovery. What is less clearly understood are the beneficial or detrimental side effects when taking sustainability issues such as water recyclability into consideration. Efforts have been directed to include these aspects in the leach test design in order to try and identify the process route with an overall best score rather than focus on recovery only. The most important issues, other than straightforward gold recovery are cyanide, thiocyanate, arsenic, mercury (mainly as a result of reprocessing old tailings deposits), and discharge salt loads, as well as overall water and power consumption.

The projects conducted so far include investigating leach dynamics under different oxygen management strategies. A key finding is that the metallurgy and leach dynamics are frequently very specific to the mineralogy of the sample, and to the methods of comminution and concentration employed. For example, fine grinding can increase the leaching rate of gold, but may also mobilise more cyanide-consuming minerals, in which case staged cyanide additions would be beneficial. The leach dynamics can also be influenced by the early or late formation of weak acid dissociable (WAD) cyanide species.

Some of the larger projects undertaken demonstrated the benefits of focusing on gold dissolution, but also more aggressively reagent consumptions and resulting sustainability issues in order to identify viable options at an early stage.

The subject of oxygen management during gold leaching has received increased attention, Mintek has worked successfully in collaboration with outside consultants on clients’ projects aimed at defining the actual oxygen need in relation to target ores and variations within these, and will endeavour to establish a centre of excellence around this topic in collaboration with gas suppliers.

An area of renewed focus is the question of geochemical stability of tailings with respect to issues such as arsenic (and almost certainly to follow) uranium leaching under differing environmental conditions.

Mintek is continuing with a desktop study to develop a holistic view of gold processing. This project, which is funded through the Science Vote, is considering various unit operations (ultrafine milling, high-pressure grinding rolls, gravity, flotation and sequential flotation, ore sorting, alternative lixivants, carbon/resin adsorption, pre-, bio- and pressure oxidation, from the point of view of both gold recovery and sustainability (power, water usage etc.).

Cyanide management

Mintek participated in a gap and full ICMI certification audit on Sasol Polymers’ Midland cyanide production and transport facility, resulting in the re-certification of both cyanide-related businesses (the cyanide transport section of Sasol Infrachem was the first global transporter to be re-certified under the code). Mintek took the role of Technical Expert Auditor in these exercises, with Eagle Environmental as Lead Auditor. A limited pre-audit site assessment targeting the cyanide levels at process, backfill and TSF (Tailings Storage Facility) levels was conducted for the Harmony Gold Mining Company Limited Kusasalethu gold plant.

Compliance-based analytical service work continued throughout, albeit at reduced levels due to the increasing logistical constraints.

In response to clients’ needs, the focus at Mintek has shifted from straightforward compliance targeting to process enhancement by addressing underlying issues such as excessive reagent consumptions and improved plant control. This has resulted in a number of collaborative projects involving site- and laboratory test work.

In association with an independent consultant, the influence of fine milling and oxygen management on cyanide consumption were investigated for Randgold Resources’ Tongon project, to determine the size of oxygen plant needed. Process simulation was also carried out on two types of ore from the Massawa project, and a second phase of work may be undertaken in 2010.
Platinum Group Metals Industry

UNDER THE STRATEGIC ALLIANCE BETWEEN JUBILEE PLATINUM AND SYLVANIA RESOURCES, a smelting trial was conducted in Mintek’s ConRoast demonstration smelter on low-grade PGM concentrate from Sylvania’s chromite tailings recovery operations.

Approximately 99 per cent of the PGMs were recovered from the concentrate, which contained an initial 85 grams per ton precious metals and 7 per cent chromium. Sylvania and Jubilee plan to trial-smelt low grade concentrates from other dump operations, as well as concentrates produced from a bulk sampling programme at Sylvania’s Grass Valley Platreef project in the northern limb of the Bushveld Complex.

Extensive comminution, heavy media separation, and flotation testwork was carried out in support of the feasibility study for Northam Platinum’s Booyendal project in the eastern Bushveld Complex. The study was concluded in the last quarter of 2009. Northam plans to develop the project using a modular approach, with the first stage producing some 130 000 ounces platinum, palladium, rhodium, and gold per annum.

1. Physical vapour deposition apparatus for applying sub-micrometre films of precious metals.
2. Pilot plant flotation exercise for a PGM project.
3. Atomisation of platinum to produce material for powder metallurgical applications.
4. Tapping PGM-bearing alloy from the ConRoast demonstration smelter.
In regard to Sheba’s Ridge, further work is planned to optimise the concentrator design using a simpler flowsheet.

Laboratory-scale comminution and flotation tests were conducted on several hundred kilograms of Merensky and UG2 core samples from Nkwe Platinum’s Garatau project, in support of the bankable feasibility study led by TWP Projects.

The first stage of testwork was completed to develop a metallurgical flowsheet for the recovery of PGMs from chromite tailings for Pan African Resources’ Phoenix chrome tailings retreatment project. A similar project was done to investigate the recovery of PGMs from chromite spiral plant tailings for Tharisa Resources.

Process optimisation investigations were completed for Sylvania Resources on the Steelpoort, Millsell, Mooinooi, and Lannex chrome tailings retreatment plants, particularly to gauge the effectiveness of stirred media milling in increasing PGM liberation and recovery. Work is ongoing on the Doornbosch and Tweefontein operations.

Feed characterisation, laboratory testwork and a short pilot-plant run were conducted to recover PGMs from Impala Platinum’s Merensky Reef tailings dams. The company plans to build a recovery plant after completing its Shaft 17 and Shaft 19 projects.

Significant effort (funded by the Science Vote) has been applied to assessing variability of UG2 ores from various parts of the Bushveld Complex, with a view to understanding the effect of regional variations on metallurgical performance. The current phase of the work will ultimately be incorporated in a Ph.D. thesis.

**PGM Characterisation**

A major project has been running since 2008 on the automated characterisation of PGMs, particularly grains less than 10 micrometres in size (which are typical of UG2-type ores) using the scanning electron microscope (SEM), with the focus on increasing the reliability of the data and capacity development. Coupled with this, quality assurance and control procedures are evaluated to ensure quality criteria are met.

An automated SEM study was undertaken of the PGM distribution across a UG2 primary rougher circuit, where about 80 per cent of the PGM recovery takes place, to investigate whether flotation characteristics can be adequately described using mineralogical parameters such as liberation index, sulphide-gangue relationships, and size distribution. It was found

1. A bulk sample of platinum ore arrives at Mintek for process testwork.
2. A cascade of circular flotation cells.
3. Mintek’s 1 ton per hour pilot flotation plant.
4. Screening a pulped PGM sample.
that flotation parameters describe the behaviour of the PGMs fairly well where large changes in PGM concentration occur, but larger data sets are required where the concentrate grades in adjacent flotation cells in a concentrate bank are similar. In particular, the complex interplay between floatable and non-floatable gangue, PGMs, and base metal sulphides needs to be taken into account.

Two M.Sc. research projects, one on the relationship between the PGMs and base metals and the other on data verification, will be completed during 2010. In order to handle the large volumes of data that are generated by the commercial automated SEM system, a processing application was developed through a collaborative effort between the Mineralogy and Measurement and Control Divisions, that takes outputs from the automated SEM and converts them into more meaningful mineralogical parameters.

Building on this work, the metallurgical significance of the mineralogical parameters was further investigated, so as to provide a metallurgically-meaningful output. A new software application has been developed, which examines the mineralogical and other data on a grain-by-grain basis, and produces an output that highlights the metallurgical properties of the PGM-bearing particles, including quantitative information on the potential recovery and the reasons for recovery or losses. This, together with other diagnostic testwork, will assist the metallurgist to make informed decisions regarding the performance of a flotation plant.

Mintek has also developed an automated software tool towards the quantitative characterisation of PGM-bearing particles using a SEM. The X-ray signals from the sample are analysed in a novel way, which allows accurate identification of small mineral particles at resolutions down to 1 micrometre. An agreement with an international manufacturer of SEMs was signed in 2009, for incorporation of this tool in their software, and a product is planned for completion in 2010.

A new state-of-the-art SEM was installed in the Mineralogy Division in 2009 to add additional capabilities and value to regular optical mineralogical investigations. The superior imaging capabilities of this instrument provide textural and grain size information via high resolution secondary electron (SE) and backscattered electron (BSE) images. The system also contains a high count rate energy dispersive spectrometer (EDS), which can provide quantitative chemical information on the minerals present in a sample, as well as high speed elemental x-ray maps.

In 2010, Mintek will be starting a project, in collaboration with the South African Nuclear Energy Corporation (Neacs), on the development of computer aided tomography (CAT) methods, using X-rays and neutrons, to assist the optimisation of mineral beneficiation processes. This is aimed at obtaining three-dimensional information from mineral and plant samples to complement the two-dimensional information gained from current mineralogical techniques.

HySA/Catalysis Competence Centre

Mintek and its partners at the University of Cape Town (UCT) have been appointed to establish the HySA/Catalysis Competence Centre as part of the DST’s National Hydrogen and Fuel Cell Technologies Research, Development and Innovation Strategy. In this past year, the Centre at Mintek has seen the arrival of four FuelCon fuel cell test stations, four fuel cell test fixtures, a hydrogen generator, and an ultrasonic spray coater. This equipment will provide HySA/Catalysis with a comprehensive facility for electrocatalyst and membrane electrode assembly (MEA) fabrication and fuel cell stack assembly.

The performance of single cells and short stacks will be characterised under simulated operating conditions applicable to each application that the HySA Programme aims to develop, namely portable power, combined heat and power, and vehicle systems. The Centre has also procured a Joel-2100F high resolution transmission electron microscope (HRTEM) that is set to be fully operational by June 2010. This instrument will be crucial in the characterisation of fuel cell catalysts at the nano-scale and will contribute significantly to the development of novel catalysts by the Centre in future.

On the research front, the focus has been on the laboratory-scale preparation of platinum and platinum-ruthenium fuel cell catalysts for hydrogen and direct methanol fuel cells respectively. The aim of producing laboratory-scale materials of similar electrochemical performance to commercially available materials has been met, but these catalysts still require validation in actual fuel cells. Once validated, the focus will be on the development of methods for the industrial-scale production of these materials while maintaining the performance.

The development of novel catalyst materials continues in parallel, and attention has been placed on developing novel carbon aero-gels as supports for platinum catalysts. These highly porous carbons are expected to have benefit in the electrode catalyst layers by limiting gas diffusion resistance through the layer, which limits fuel cell performance.

Another area of research was a review and techno-economic evaluation of possible solar hydrogen production through water-splitting technologies based on photocatalysts and photoelectrochemical cells (PECs). The outlook for cheap hydrogen from direct water splitting by solar light (even with idealised systems) is poor, and the estimated costs of production (between US$13 and US$37 per kilogram H₂) far exceed the accepted US$3 per kilogram target for a viable “hydrogen economy”. As such, the Centre has recommended that future HySA Programme resources are not placed in R&D in this area. The study does not rule out other solar technologies such as solar-thermal electricity production coupled with efficient water electrolyzers, but these require further techno-economic analysis.
Ferrous Metals Industry

TESTWORK ON THE UPGRADING OF IRON ORE to support pre-feasibility and feasibility studies remained an important area of commercial interest. Bench and pilot scale studies for the Pietersburg Iron Company on the upgrading of materials from a low-grade magnetite deposit focused on novel approaches to fines beneficiation, ranging from milling, using a high pressure grinding roll (HPGR), to sequential magnetic upgrading, to target specification. Iron ore from new projects tends to be of a lower grade, and the mineralogy of the deposits is more complex. Collaborative studies were conducted with Kumba on the SLon technology, during which Mintek developed the first phase of a user manual setting out operational parameters for various ore applications.

A large amount of small-scale tank and heap leaching testwork was conducted on samples from African Eagle Resources’ Dutwa nickel laterite project in Tanzania. The testwork showed that the ore is unusually amenable to acid leaching, with good nickel extraction, very low acid consumption and very fast leach kinetics compared to other nickel laterites around the world. Similar testwork is planned in 2010 for the Ngasamo laterite deposit, which is adjacent to the main Dutwa deposit. Acid leaching tests were also carried out on drill samples from Zanzui, African Eagle’s second Tanzanian laterite project, with results comparable to those from Dutwa.

Prophecy Resources has commissioned Mintek, in conjunction with Wardrop Engineering, to conduct metallurgical testing on a bulk sample from its Lynn Lake nickel sulphide deposit in Manitoba, Canada. The project, which includes flotation

1. Casting grinding balls from an experimental alloy.
2. An industrial ferrochromium furnace.
3. Smelting a titaniferous magnetite concentrate.
method development, production of concentrate, and tank bioleaching amenability and optimisation tests, is scheduled to start in the second quarter of 2010. The results, if favourable, will be incorporated into the planned feasibility study. A number of enquiries for similar work have been received, indicating renewed interest in agitated-tank bioleaching for on-site metal recovery, rather than producing concentrate for third-party smelting.

Mintek was approached by DRA Mineral Projects Ltd (DRA) on behalf of Uranium Star Corporation to evaluate a hydrometallurgical process route to recover vanadium from the Green Giant vanadium deposit in south western Madagascar. The work consisted of mineralogical characterisation (including X-ray diffraction, optical microscopy and scanning electron microscopy), atmospheric acid and alkaline leaching, an evaluation of the potential for upfront pre-concentration by physical separation techniques and flotation.

A 200 kilowatt smelting test in a DC furnace was successful in producing significant quantities of silicon metal for the first time. The aim was ultimately to develop an improved method of producing solar grade silicon. However, owing to the introduction of significant contamination by metallic iron during tapping, it was concluded that this route is not worth pursuing further.

A smelting test on more than 25 tons of nickel concentrate successfully demonstrated the beneficial effects of careful control of the operating conditions on the overall process performance. The 3.2 megavolt-ampere DC furnace was operated in submerged-arc mode instead of with an open arc, and with a “black top” of unreacted feed material on top of the molten slag, so as to simulate a production-scale AC furnace. This work constituted the second phase of an investigation that was begun for Xstrata Nickel in 2008 (Annual Report 2009).

Simulation work using Mintek’s ROSES electrode temperature profile simulator has shown that it should be possible to use a Söderberg self-baking electrode in a DC furnace, with resulting savings in electrode costs. A self-baking electrode was pilot-tested in the 3.2 megavolt-ampere DC furnace for more than eight hours at temperatures up to 600ºC. The electrode displayed good mechanical properties, and there were no major differences in the arc characteristics compared with pre-baked graphite electrodes. Using a direct current would be expected to result in more even baking and less stress on the electrode, which is an important consideration when using very large-diameter electrodes.
A Ph.D. study was completed on the dynamic modelling of the arc in a DC furnace using computational fluid dynamics, and the modelling results verified using high-speed photography. A key finding is that there are distinct short-term transition effects, of the order of less than one millisecond, in the behaviour of the arc. These are related to the furnace current and arc length, and could potentially have an effect on power supply control. Mintek has started a collaborative project with Zurich-based power and automation technology group ABB, who are interested in applying the results of the research to the design of improved power supply equipment for DC furnaces.

The site for a new X-ray fluorescence sorter from Rados SA of Russia is being prepared, and the unit is expected to be operational by the end of July 2010. This is a complementary technique to optical sorting, based on online X-ray fluorescence analysis of the surface of each particle followed by physical sorting rather than pneumatic ejection. The main areas of focus that differentiate this sorter from optical or X-ray transmission sorting include dry upgrading of manganese ores to a specified manganese-to-iron ratio, and detection and sorting of coarse kibellite ore from waste. The direct surface assay by XRF scan has also found interest in uranium ore upgrading and waste removal from sulphide orebodies.

**Process Modelling**

The latest developments in modelling of physical separation processes include circuit simulations of wet low-intensity magnetic separation (LIMS) to produce high-purity magnetite of various size and grade specifications. The modelling of spiral and shaking table separators has made extensive use of SEM imaging to incorporate feed and product size, density, grade and shape data into a single model framework.

**Improved Grinding Media**

This DST-Innovation Fund sponsored project to develop a cheaper and more cost-effective grinding ball for use in the PGM mining industry (Annual Report 2009) progressed from the pilot-plant scale production of balls at Mintek to industrial-scale production at Prima Industrial foundry in mid-2009. The original list of fifteen promising chemistries was reduced to four after having passed all the performance gates. Batches of about 500 balls of each chemistry were produced at Prima over a period of five months. Thereafter, 300 balls from each batch were selected, marked and weighed in preparation for Marked Ball Test (MBT) experiments in one of the grinding mills at Anglo Platinum’s Union Section concentrator in North West Province. The MBT experiments, which are the penultimate phase of the project, will begin in mid-June 2010, and will be followed by Full Mill Charge (FMC) trials with the most promising chemistry for a period of six months. After this final phase of the project, commercialisation will proceed in earnest.

**Foundry Support**

In the 2009/10 financial period, Mintek was awarded a R1-million project by the National Foundry Technology Network (NFTN), an initiative of the Department of Trade and Industry (DTI), to provide technology and provide manufacturing assistance to ten sand foundry firms. This project was undertaken under the auspices of the Sand Foundry Improvement Programme and was executed in partnership with the University of Johannesburg’s Metal Casting Technology Station, Freiberg Technical University in Germany, the Federal Association of the German Foundry Industry, and the Automotive Industry Development Centre.

The outputs from this project showed that the South African foundry industry is critically under-resourced in key areas such as skills development and training, access to world-class testing facilities and R&D centres to support new product development, and assistance with the optimisation of production processes by resolving process and material flow challenges. Technical assistance in these key areas will help the industry to become a world-class provider of foundry products to both the local and export markets. Mintek has already begun responding to these industry needs by initiating foundry-related R&D programmes in areas such as modelling and simulation of foundry processes and by providing customised metallurgical testing services of castings through the Metals Technology Centre (MTC) at Mintek.

**Materials Testing**

Mintek has begun a Science Vote-funded project to expand its capabilities around materials-related issues in the petrochemical industry. These include metal dusting and naphthenic acid corrosion. The aim of the naphthenic acid corrosion project is to develop a test methodology to evaluate the extent of corrosion that can be anticipated when crude oils containing various types of naphthenic acid are processed. This will greatly reduce the corrosion risks associated with processing opportunity crude oils. The MTC has the only laboratory in South Africa for investigating the susceptibility of alloys to corrosion and hydrogen-induced cracking under the “sour service” (wet hydrogen sulphide environments) that are commonly encountered in this sector, and most materials used in the local petrochemical industry, as well as seamless pipes that are manufactured in South Africa for export, which are tested in this facility.
THE BIOTECHNOLOGY DIVISION TRANSFERRED INTO PREMISES AT MINTEK that were previously leased by a tenant company. The comprehensive laboratory and pilot plant facilities are particularly well suited to biotechnology applications, particularly extended heap-leach simulation in temperature-controlled columns up to 6 metres in height. The move also facilitates the expansion that is required to undertake minerals-related biotechnology research in new areas.

Negotiations were concluded and a contract signed with the National Iranian Copper Industries Company (NICICo) for the full-scale implementation of Mintek’s high-temperature heap bioleaching technology at their Darehzar copper mine near the Sarcheshmeh Copper Complex in Iran. The engineering specifications are now being drafted, after which NICICo will invite tenders for Engineering, Procurement, Construction and Management (EPCM). This technology is the result of the combined efforts of Mintek and NICICo over a period of several years, under the terms of a Collaboration Agreement signed between NICICo and Mintek in 2004.

A large-scale project for a major multinational mining company to test the amenability of a Chilean copper ore to heap
bioleaching is under way, and will run until the first quarter of 2011. A similar programme of testwork on a refractory chalcopyrite copper ore for Japan Oil, Gas and Metals National Corporation (JOGMEC) will be completed early in the second half of 2010.

The MetRiX resin-in-pulp technology was evaluated for the recovery of copper and cobalt from residue dumps. The investigations also included the potential for producing copper metal and an upgraded cobalt product from the ion-exchange eluate. A preliminary techno-economic evaluation of an ion-exchange fibre tested for the removal of copper from cobalt electrolyte showed major potential savings compared with granular ion-exchange resin.

Systematic investigations spanning several years have now culminated in the formulation of optimised process parameters that can be applied with confidence for tank bioleaching of chalcopyrite. The process options include the use of thermophilic (high-temperature) organisms and the use of controlled redox conditions with moderate thermophiles.

Extensive investigations have been conducted into the microbiology of heap bioleach processes, in an attempt to elucidate the correlation between microbial cell types and numbers and the changes in the chemical and physical processes in the heap over time. The need to understand microbial succession in heaps has become more critical with the advent of high-temperature heap leaching of chalcopyrite ores, since preservation of heat within the heap is essential in order to overcome the passivation of chalcopyrite. A research programme has started on the geomechanical and geochemical properties of ores suitable for heap leaching, which is aimed at acquiring more fundamental information for improved modelling and interpretation of heap leach processes.

The characterisation and production of industrial biomolecules, such as extracellular polysaccharides (EPS), and their wider process applications, is being investigated. EPS, which is produced by bioleaching micro-organisms to facilitate cell attachment to mineral surfaces, plays an important role in heap leach processes, and is also intimately involved in the microbial mechanisms for iron and sulphur oxidation. Very promising results have been obtained at the laboratory scale using EPS as a bioflotation reagent, and current testwork is aimed at demonstrating the process at a larger scale.

Further flotation work was undertaken for Discovery Metals’ Boseto copper-silver project in Botswana to confirm the grades and recoveries for the bankable feasibility study.

Dense media separation to remove barren material, and flotation of oxide and sulphide samples, was carried out for the Omifomire copper project in Namibia. A second phase of work on ore variability is planned for 2010.

Laboratory work was started on flowsheet optimisation for the Bisha gold and base metals project in Eritrea for Nevsun Resources, and will continue into 2010.

Laboratory-scale testwork was conducted on a pyrometallurgical method to process zinc and lead oxide ores from the Accha and Yanque projects in Peru for Zincore Metals. The results showed that reductive roasting could be used to achieve recoveries of up to 96 per cent of the zinc and 88 per cent of the lead. Previous testing of the Accha District ores, which focused on producing a flotation concentrate (Annual Report 2008), met with limited success. This work was conducted under the supervision of Metalicon Process Consulting.

Research on hematite precipitation from ferric chloride liquors under atmospheric conditions, using a potentially energy-efficient hydrometallurgical processing route, showed not only that hydrochloric acid as reagent can be successfully regenerated, but preliminary investigations in industry have indicated that the hematite product also has the potential to be saleable as a high-value pigment for paints rather than merely as feed to iron- and steelmaking processes.

Advances have been made in the understanding of the fundamental chemistry pertaining to the oxidative removal of both iron and manganese from base metal value streams using an air/\(\text{SO}_2\) gas mixture as reagent. This has also been successfully confirmed on a 10-litre pilot scale setup. Mintek plans this year to scale up this circuit to a 20 cubic metre fully automated plant. Testing of the process on a larger scale is expected to attract collaboration from industry, with the aim of implementing the process in an energy-efficient form commercially.

A 10 kilogram per hour bubbling fluid-bed chlorination reactor for producing titanium tetrachloride (\(\text{TiCl}_4\)) was constructed and commissioned, and is currently being modified to enable continuous sustained operations. A Kroll reactor with a capacity of 1 kilogram per batch has been commissioned, and the first test run to produce titanium sponge is scheduled for the second quarter of 2010. In previous work, titanium powder was successfully produced from commercial sponge by hydrogenation and milling, and was used to produce a range of titanium alloys by mechanical alloying, compaction and sintering. The next phase of work will involve alloy manufacture using sponge from the Kroll reactor. Mintek also plans to test other reductants for producing titanium sponge, in addition to the liquid magnesium usually employed in the Kroll process. This project forms part of the Light Metals Development Network of the DST’s Advanced Metals Initiative, which aims to stimulate the development of a primary titanium industry in South Africa.
LABORATORY-SCALE COMMINUTION, FLOTATION, AND REAGENT OPTIMISATION TESTWORK was carried out on samples from Sephaku Holdings’ Nokeng fluor spar project in north-eastern Gauteng Province. Two ore types – the Plattekop fluorite-hematite ore and the Outwash Fan placer-type ore – were tested in order to maximise the concentrate grade. The work confirmed that a concentrate grading of 97.2 per cent CaF₂ can be produced. The optimisation process will continue in 2010. Sephaku intends developing a mine producing 130 000 tons of acid-grade fluor spar per annum by 2012.

A project is continuing on the mineralogical characterisation of “semi-precious” (ornamental) minerals. This is aimed at assisting “second economy” miners to properly identify and grade material, and to establish a verification system by way of a certified trading chain.

The successful dry rejection of shale from coarse coals (<150mm >15mm) using X-Ray transmission sorting has resulted in a full-scale chute-fed sorter being installed to clean steam coal at the Arnot power station.

An area of increasing interest is the beneficiation of phosphate. Preliminary mineralogical investigative studies and bench-scale size distribution evaluation of phosphate deportment has been
conducted on material from southern African deposits, and Mintek has started working on a number of additional phosphate upgrading studies on samples from Angola, Tanzania, Zambia and Peru.

**Uranium**

As part of the current changes in global energy dynamics, the uranium sector has grown rapidly, particularly in southern Africa. Uranium-related activities have become one of the largest growth areas at Mintek. Many of the deposits under investigation are relatively low grade, and significant development effort has been expended on upgrading of the ore by techniques that include flotation, pre-sorting and gravity concentration. In addition, significant effort has gone into characterising the comminution behaviour of a range of ores, as this has a significant impact on the energy requirements and processing costs.

Agitated tank leaching testwork was conducted for the Uranex NL’s Manyoni uranium project in Tanzania as part of the pre-feasibility study managed by AMC Consultants. The mineralisation consists of secondary uranium (schrockingerite and carnotite) in playa lake sediments. The results showed that uranium recoveries of greater than 90 per cent can be achieved within short time frames. A second phase of multidisciplinary testwork, which will include column tests for heap leaching amenability, has been awarded.

Agitated-tank and heap bioleaching testwork has been conducted on Karoo-type (sandstone-hosted) and alaskite (Rössing-type) ores. Further metallurgical testwork in the form of column leaches was conducted for African Energy Resources in support of the bankable feasibility study on the Chirundu uranium project in Zambia. Preliminary leaching testwork was completed on samples from the Mooifontein uranium prospect in the Karoo for El Nino Mining.

A modelling exercise was undertaken on the NIMCIX adsorption and elution columns at the Trekkkopje uranium project in Namibia to determine the optimum operating cycles and predict the effect of operational changes on performance. A site visit was conducted to assist in optimising the operation, and recommendations made for future designs for the phase 2 (MIDI) and phase 3 (MAXI) circuits. Mintek previously conducted process design for Trekkopje (Annual Report 2008), which is the world’s first uranium mine to use an alkaline heap leach process.

Physical beneficiation testwork was conducted on samples on uranium-bearing aeolian sands (the Tubas Red Sand deposit) from Deep Yellow Limited’s Omaholea uranium project in Namibia. Scrubbing and attritioning resulted in 90 per cent of the \( \text{U}_3\text{O}_8 \) being concentrated into 22 per cent of the feed. A second phase of work will be conducted in 2010 on drill-core material from the INCA deposit, which consists of both primary and secondary mineralisation in granitic and metamorphic rocks. This work is being undertaken as part of the project feasibility study managed by SNC Lavelin.

Comminution, mineralogical characterisation, and leaching testwork to determine ore variability and optimum leach conditions were conducted on drill core samples from the SK orebody for Rössing Uranium. Mining of the SK orebody, which is about 1.5 kilometres east of the existing SJ open pit, forms part of Rössing’s expansion programme to increase production and extend the life of the mine beyond 2021.

A third phase of leaching and solvent extraction was completed for Areva’s Bakouma uranium deposit in the Central African Republic. The work, which was conducted on a composit ed bulk sample, involved screening and milling, optimisation and confirmation of leach efficiencies, a bulk leach to produce slurry for solid-liquid separation (conducted by an external consultant) prior to solvent extraction testwork, and solvent extraction employing a two-cycle circuit. A slurry sample was prepared from the leach residue and synthetic raffinate for further environmental tests by Golder and Associates.

A bulk leach was conducted for Gold Fields, together with carbon-in-leach for gold recovery, as part of an investigation into a dump reclamation project in the Free State, and a flotation exercise for Harmony Gold Mining Company Limited, with uranium extraction scheduled to follow in 2010. A mini-plant, including a Bateman Pulsed Column, was run for Rand Uranium.

Owing to the increase in demand for uranium resource evaluation studies, different lixiviants have been evaluated in investigations to develop a diagnostic leaching procedure for uranium. Such a procedure could provide information about the amount of liberated uranium in a sample, and the fractions associated with different gangue minerals, which would assist in the development of the most appropriate extraction process and help predict plant performance.

The bioleaching of primary uranium ores has been shown to hold great potential, and several commercial enquiries have been received. Tank bioleaching of uranium-containing concentrates and ores is also being revisited. Current test work is focused on the use of thermophilic organisms to accelerate the leach kinetics. The reaction proceeds through the oxidation of pyrite (either a natural constituent of the ore or added in the form of concentrate) to sulphuric acid and ferric iron, which then leaches the uranium.

Intensive investigations have been conducted on the use of the MetRIX resin-in-pulp technology to recover uranium from low
grade pulps, with the evaluation of different RIP-grade resins and various process improvements.

The extraction of uranium in Bateman Pulsed Columns is standard technology, but stripping is not conducted on full scale as yet due to the perceived risk associated with neutralisation inside the column. Stripping of uranium from Alamine 336 reagent was tested in a column 40 millimetres in internal diameter and 6 metres in height at Mintek in collaboration with Bateman, and the results confirmed that neutralisation in the column during stripping was effective. When some precipitate formed in the column, it re-dissolved prior to the streams exiting the column.

A project was begun to investigate the possibility of operating a true continuous countercurrent resin elution column. The main application of such a system would be in the uranium industry. Many systems that claim to be continuous are in fact batch-continuous, and are stopped periodically to allow resin withdrawal in a direction opposite to the solution flow. A true countercurrent elution process would offer enormous advantages in terms of savings on resin and capital costs, higher eluate grades (which are essential for uranium recovery by direct precipitation), and cleaner stripped resin (lower barren values).

Mintek has conducted an extensive testwork programme using the high-pressure grinding roll (HPGR) on uranium, gold and copper ores, with the emphasis on optimal integration of the technology in the comminution circuit in order to save energy and provide better liberation. Most projects have involved the quantification of downstream benefits. Mintek has developed a testwork procedure to quantify the competence of HPGR flakes generated and is actively involved in research aiming at predicting HPGR performance from piston die tests. A HPGR simulator is also currently being developed to predict HPGR performance and for use online to optimise HPGR performance.

**Diamond Provenance Studies**

The SA Diamond and Precious Metals Regulator (SADPMR) is funding a project aimed at developing a method for determining the geological source of rough alluvial diamonds, based on a combination of their physical characteristics and trace element analysis. If successful, such a technique would help to curb theft and illegal mining, and assist in preventing “conflict diamonds” from entering the legitimate trade in accordance with the principles of the Kimberley Process certification scheme.

The SADPMR-Mintek Diamond Provenance laboratory was officially opened in June 2009. Method development for the trace element studies, using a Laser Ablation Inductively

**Coupled Plasma Mass Spectrometer (LA-ICP-MS),** was carried out using a high-carbon based material from Macquarie University in Australia as a standard, and morphological and Fourier Transform Infra-Red (FTIR) spectrometry measurements have been completed on ten parcels of alluvial and kimberlitic diamonds from South Africa, Ghana, the Democratic Republic of Congo, and the Central African Republic. The FTIR results, which provide information on the nitrogen content as well as the position of nitrogen in the diamond crystal lattice, were interpreted with the aid of deconvolution software provided by De Beers’ Diamond Trading Company (DTC) Research Centre and adapted for the Mintek spectrometer by the Measurement and Control Division. Trace element analyses using the LA-ICP-MS are currently being run on a select group of 30 elements known to occur in diamonds, including the rare earth elements, and will be completed in the second half of 2010.

**Water treatment**

Investigations of possible changes to the flowsheet of the Savmin process for ameliorating acid mine drainage suggest that the capital and operating costs can be reduced significantly by incorporating a novel technique for solid-liquid separation, making the process more cost-effective.

Another area of interest to Mintek that will be explored during 2010 is the bio-remediation of water and effluents. Typically, water-related environmental problems associated with polluting discharges from mines are due to acid mine drainage and leaching of contaminants into the groundwater. This will be an interdivisional project, and preliminary investigations of potential opportunities have begun in order to develop a focused research strategy.