

# Science

World class science and technology is at our core. We have world class scientists and we use our world class expertise to solve complex problems for our customers, drive growth for JM and help make the world cleaner and healthier. In a world which is becoming increasingly challenging, our expertise in science and our ability to scale it up, is a competitive advantage. That competitive advantage enables us to build close collaborative relationships with current and future customers.

Strategic Report

# We apply our science and technology expertise in high margin, technology driven growth markets.

We choose markets where the combination of our broad expertise and our customer focus gives us leadership. We then sustain our leadership positions through a virtuous circle of investment in research and development.

### Our science and technology is our source of competitive advantage

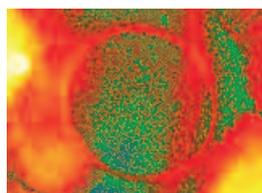
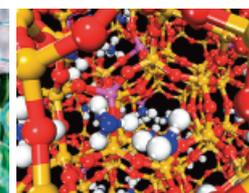
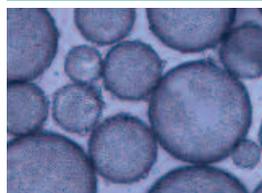
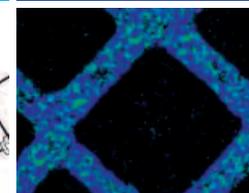
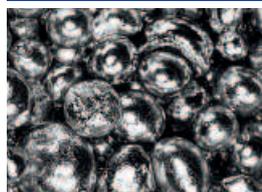
We invest in it and in our talent. Our skill and knowledge are acknowledged across the academic and commercial scientific community and amongst our customers.

We have nine core areas of world class scientific capability, developed over many years. Together they give us the ability to provide fundamental insights about materials, their design and then the control of their activity through chemical and functional manipulation.

But it is not just about these scientific capabilities alone. Our competitive advantage is in combining knowledge of the fundamental science and technology, with commercial and scalable solutions, potentially customised for each and every customer. This combination allows us to outperform in our target markets and creates high barriers to entry.

We focus on the complex and the difficult. And we don't compete on price – we win based on our technology. Our scientific capabilities give us the opportunities to drive growth.

### World class science capabilities

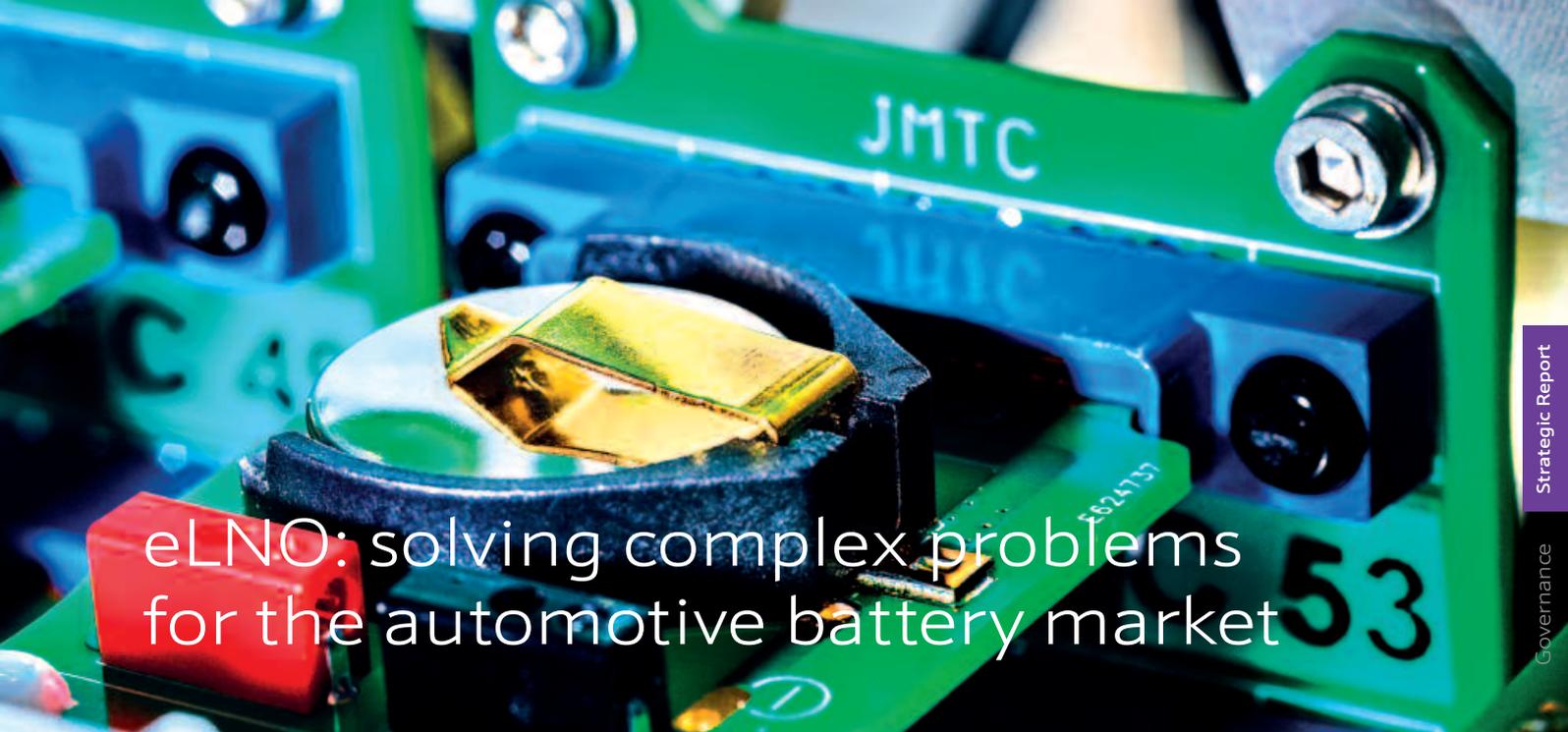
 Characterisation and modelling	 Chemical synthesis	 Material design and engineering
 Product formulation	 Process optimisation	 Surface chemistry and coatings
 Pgm chemistry and metallurgy	 Catalysis and advanced materials	 Electrochemistry

### Cleverly applied

 Provision of customised solutions
 Development of new and next generation products
 Scale up of complex manufacturing

### Value for JM

Solutions for customers



# eLNO: solving complex problems for the automotive battery market

**Enabling people to breathe cleaner air is close to our heart and evident in many of our current markets and products. As alternative powertrains, such as battery powered vehicles, become more mainstream and governments legislate to support their adoption, our researchers are at the forefront of technological advances and development of materials – providing customers with the performance and consumers with the confidence required of battery powered vehicles. Adoption of battery powered vehicles will have a positive impact on cleaner air, and that's important to us.**

Last September, we announced our investment in automotive battery materials and the new cathode material – eLNO™.

We developed this material through a truly collaborative programme, from nine locations across the UK, Germany and North America, applying our knowledge of base metal chemistry, formulation and testing, modelling and electrochemistry across the materials supply chain. Our relationship with the automotive industry, and understanding their requirements for energy density, power, lifetime and security of supply for materials, have focused our effort on the key enablers for this technology. Our innovation delivers a step change in energy density that, in the end, improves both performance and cost to drive mass electric vehicle adoption across vehicle platforms.

More than a materials manufacturer, we are committed to using our core competencies to understand electrode structure and applications testing to further drive up energy density of our cathode materials. Together, our knowledge of materials engineering, coatings science and electrochemistry span all aspects important to battery material performance.

This deep appreciation of how the cathode material operates and the structure and function of the materials at an atomic scale means we can model and predict how changes to the material affect performance. Combined with applications testing we understand how our materials perform under different operating conditions which enables us to deliver the material's performance, lifetime and safety specifications required by our customers.

We use this expertise to optimise our materials for different automotive customers and platforms. Working with our teams on formulation, scale up, applications testing, and manufacturing means we can translate these insights into a deliverable product. In 2016, the battery market represented 50% of the global cobalt demand, compared to 36% of the global lithium demand. With the recent increase in cobalt prices, our ability to thrift cobalt, much like we've done in platinum group metals in autocatalysts for well over 40 years, is a key market differentiator for JM.

Strategic Report

**Innovating to realise value**

Innovation is realising value from knowledge. We do this by identifying a customer need and understanding the value that can be delivered through applying our science. This could be a new technology in a new area or a next generation product developed through refining and optimising. We focus on solutions for cleaner air, improving people's health and the most efficient use of our planet's natural resources. Our strength comes from the interrelationship of our world class science capabilities and the value they deliver when applied to a solution to a customer's complex, difficult problem.

We do not innovate in isolation and it's our strength of understanding across the value chain that accelerates our progress. We work closely with universities around the world to supplement our knowledge. We also sponsor students through their PhDs which allows us to access a stream of talented young scientists and engineers at the forefront of scientific discovery.

We are proud of our science and technology. Success comes from combining our core capabilities with smart manufacturing to develop new products and processes. This approach is important from initial R&D right through to customer support and collaboration.

Our broad science capabilities enable us to design new materials. Our deep expertise in characterisation and modelling underpins everything. We use this capability to understand processes and chemistry at atomic level. Then, by combining it with our access to world class capabilities in computational modelling, we can predict how materials and catalysts will behave, deliver results faster and supply better performing, longer lasting, more cost effective products.

**Opening innovation with a new approach to collaboration**

We believe that collaboration and diversity are central to effective innovation. Bringing in new skills, fresh thinking and different perspectives is crucial. If you can combine and apply that breadth of knowledge and knowhow, you can create exponential value.

Among the many industry verticals in which we operate, the agricultural sector is familiar to us. We bring our world leading catalytic science to the manufacture of fertilisers and other agrochemical intermediates. Now we are exploring ways to use our broader capabilities, from formulations and coatings to advanced manufacturing techniques, to help develop new opportunities and address critical market challenges in the agriculture market. There is no monopoly on great ideas.

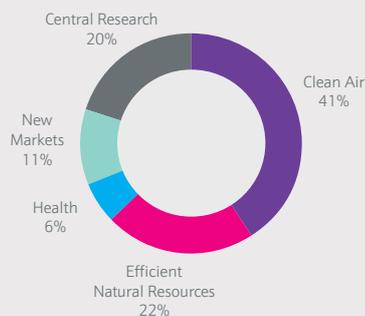
That's why, alongside the work we do within JM, we're building external partnerships with activities like our AgTech pilot programme with Cranfield University. Earlier this year, we sought applications from entrepreneurs, start-ups or businesses especially working in certain specific agricultural areas. Three companies were chosen and given an opportunity to develop their product or idea within an intense programme of collaboration and scientific and management support.

**Investing in the areas of highest potential growth**

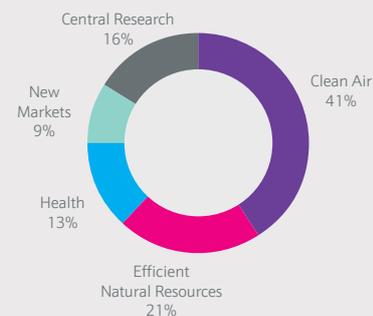
Science lies at the heart of our company. We invested £193 million in R&D in 2017/18, including £18 million of capitalised R&D, which represents 5% of sales. Our spend was 4% lower than last year, although our output was maintained, as we invested with greater discipline and efficiency into areas of higher potential return.

To ensure our R&D investment is accelerating revenue growth opportunities as effectively as possible, we apply a high level of rigour to manage and prioritise our R&D programmes. Delivery of our vision for a cleaner, healthier world requires an innovation strategy to prioritise and manage our technology investments. By looking at our strategic aims as an organisation, we can map the technologies, areas of expertise and investment we need.

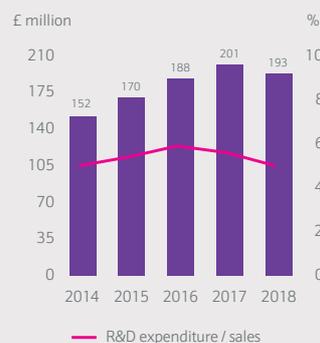
**R&D employees**



**Distribution of R&D expenditure**



**Gross R&D expenditure**



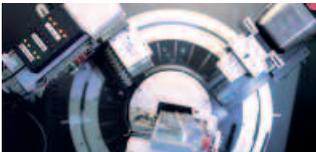
The commercial and technical leadership teams work closely to ensure objectives are aligned.

We apply active R&D portfolio management with stage gating processes and a cross cutting approach for discovering new innovations and customer solutions. This ensures we're creating new sources of growth through innovation and aligning our investments to drive higher returns. This requires a strong relationship between R&D and new business development to drive opportunity assessment in new technologies and new markets, in line with our group strategy. Our Chief Technology Officer ensures that we have the right expertise and the right oversight to investigate the opportunities in our businesses and deliver customer focused technology.

The project portfolio is underpinned by a robust New Product Introduction (NPI) process, and is reviewed to ensure it will deliver our growth ambitions from the next generation of products, to step-out technology. Having this visibility of our R&D investments means we can make sure the balance of projects is right to meet our strategic growth plans.

The majority of our 1,450 science and technology employees are based in our businesses, developing products and processes for our customers. They are supported with fundamental science from our corporate research facilities in the UK, USA and South Africa (as detailed on the map below). Together we collaborate to deliver world class science that our businesses can convert to customer solutions.

The research we undertake covers development of the next generation of products in close liaison with our customers, through to supporting the advancement of our underpinning capabilities and fundamental research to keep us at the forefront of our fields. Externally, we partner with other organisations in funded programmes supported by the UK, EU and USA, giving us access to a wider talent pool of exceptional scientists, and allowing us to explore new opportunities through collaboration whilst sharing risk.



**Savannah, USA**

- Zeolite design and manufacturing support
- Analytical chemistry



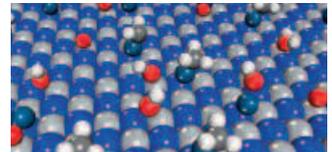
**Billingham, UK**

- Manufacturing science centre
- Zeolite powder R&D
- Reactor engineering



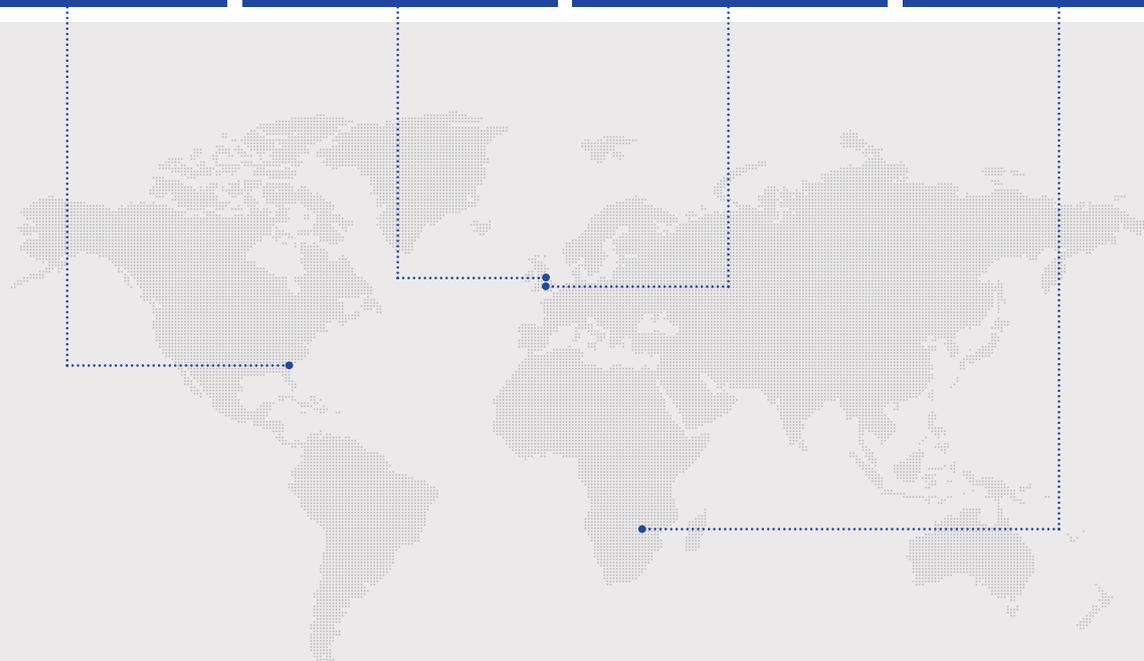
**Sonning, UK**

- Catalysts and materials
- Advanced materials characterisation
- Refining



**Pretoria, South Africa**

- Computational modelling
- Materials design



## Applying our science to new areas

**Platinum group metal (pgm) chemistry is an area of deep and longstanding expertise for JM and we look for new areas where our experience can bring benefit. One such example is an escape hood used by first responders to protect them from carbon monoxide (CO) poisoning. The problem with conventional solutions was that the catalyst for removing the CO gas was deactivated by components in the carbon adsorbent used in the masks.**

Through accessing our breadth of science capabilities and collaboration with our customer, Avon Protection, a novel pgm catalyst on a specially designed support was developed. Begun as a project funded by Anglo Platinum, our scientists screened a wide range of established and innovative materials for ambient temperature CO oxidation to find the best catalyst for use under these challenging conditions.

Our analytical experts were called in to extensively characterise the catalyst to evaluate its behaviour under different conditions. This enabled our scientists to understand the interactions between the pgm and the support and then optimise the pgm concentration whilst maintaining activity for CO reduction, which led to reduce costs.

For manufacture and scale up, our pgm and materials experts collaborated with their JM colleagues with expertise in process optimisation and powder forming to meet the customer's requirements. The outcome was a route to scale up and manufacture established in line with customer specifications and expected customer demand.

Using our catalysts, Avon Protection were able to develop the award winning Avon Protection NH15 Combo Escape Hood, a stable and lightweight hood which provides portable protection from chemical, biological, radiological and nuclear (CBRN) poisoning. In addition, and uniquely in such a small and lightweight device, it provides protection from CO poisoning.

To date, JM has provided enough catalyst for 40,000 respiratory protection devices, providing reassurance to emergency personnel who find themselves in dangerous situations daily. Thanks to JM's catalyst, these front-line people have at least 15 minutes of breathable air, providing time to get themselves to safety.

**Clever science is not all we do. At JM we develop technology solutions to complex problems which involve engineering and design of processes and reactors. Being able to do this alongside our knowledge of materials and reactions means we can gather the insight needed to make innovative changes. We applied this approach to the development of a new reactor for Fischer Tropsch technology to economically produce sustainable fuels from feedstock sources such as renewable biomass, municipal solid waste (MSW) and flared associated natural gas.**

In collaboration with BP we combined expertise in catalyst development, catalyst manufacture, plant design, process development, process design and modelling to develop an optimised Fischer Tropsch catalyst with a unique reaction enhancement device (which we call a CAN) inserted into a multi tubular fixed bed reactor. The reactor was designed to carefully manage heat transfer and pressure drop. The catalyst particle size was optimised to give excellent activity and selectivity without compromising the functionality of the reactor.

This work took many years to come to fruition, but has resulted in a system that delivers three times the productivity of a conventional multi tubular fixed bed reactor. This reduces capital expenditure by half and reduces ongoing plant operating costs. This also makes the technology more attractive and economical from small scale suitable for MSW based projects, to world scale natural gas based projects.

We are proud to have been double award winners with our partner BP, landing the Research Project Award and the Oil and Gas Award at the prestigious IChemE Awards in November 2017.

We are now progressing to build commercial size units and to licence the technology from small to large units worldwide.

## Chemical reactors: innovation by design

