White Paper on Iridium

Platinum Group Metals – the Power to *Improve Lives*

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SFA Oxford

IPA

Contents

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Overview

Iridium and its unique end-uses, trends in real life applications and future end-users and the importance of this metal for the EU

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Green hydrogen is set to play an increasing role in meeting EU climate objectives over the long term and in strengthening Europe's energy resilience in the shorter term.

The European Commission's REPowerEU Communication in May 2022 proposed to accelerate hydrogen adoption, observing that renewable hydrogen will be key to replacing natural gas, coal and oil in hard-to-decarbonise industries and transport. By 2030, REPowerEU has set a target of 20 million tonnes of hydrogen to be available per annum, derived equally from domestic renewable hydrogen production and renewable hydrogen imports. REPowerEU builds on the European Green Deal and on the Fitfor55 proposals which aim to cut carbon emissions by at least 55% by 2030.

A ten-fold increase in electrolyser manufacturing capacity – for the production of green hydrogen – was proposed by electrolyser manufacturers in Europe in May 2022, to align with these REPowerEU targets. To produce 10 million tonnes of renewable hydrogen, an installed electrolyser capacity of 90-100 GW (in terms of hydrogen output, but up to 140 GW by electricity input) would be needed. Current electrolyser manufacturing capacity in Europe is around 1.75 GW per annum; electrolyser manufacturers in Europe now aim for a combined 17.5 GW of production capacity per annum by 2025.

Two water electrolysis technologies dominate the green hydrogen production market, one of which relies on the critical metal iridium. Proton exchange membrane (PEM) and alkaline (ALK or AWE) electrolysers are currently the leading technologies for producing green hydrogen at scale; both have strong industrial support, so are likely to co-exist long term. Currently, PEM is a less mature technology than ALK, so CAPEX costs are higher, but are falling as scale increases. PEM, though, is particularly well matched with renewable energy input (wind, solar) and responds (starts to produce hydrogen) more quickly than ALK, so is able to make better use of these intermittent renewables.

Singly, and in combination, iridium's properties make it hard to beat in a wide range of established applications. Iridium's end-uses are driven by properties which are relatively rare singly, but the combination of properties – high temperature stability and chemical resistance for crucibles for making crystalline materials for electronics, high chemical resistance and catalytic activity for chemical and electrochemical uses in harsh reaction environments, and high temperature stability and mechanical strength in spark plugs for vehicle and industrial engines – gives iridium its edge.

Iridium is one of the rarest of the platinum-group metals (PGMs), with mined supply just under one-twentieth the size of that for platinum. It is concentrated in South Africa, with small contributions from Zimbabwe, Russia and North America. Iridium is essentially a by-product of platinum mining, so supply of iridium depends on continued strong demand for platinum. South Africa presents a secure supply chain for iridium (and, of course, platinum and ruthenium which also play a substantial role in the hydrogen economy), with more than 15 operating PGM mines and a huge resource base with several active projects.

Sustainable iridium use in the hydrogen economy depends on combining several factors beyond mined supply, by optimally managing iridium in both existing end-uses and in emerging hydrogen end-uses.

In existing end-uses, recycling of iridium has thus far been limited from the open loop but has some potential to increase. Substitution of iridium out of some existing end-uses, either by using alternative materials or by developing novel technologies not based on iridium, may make some more of the current mined output available for electrolysers, though there are few readily available substitution options.

As iridium use in the electrolyser market develops, there are three areas where there is some leverage to help balance the market and ensure sustainability: thrifting the loadings significantly while retaining performance and durability; embedding highly efficient closed-loop recycling; and reducing process losses. Substantial progress has already been achieved with thrifting, with further progress expected using established catalyst chemistry techniques, amply demonstrated by progress in the autocatalyst industry over the years.

Current goals for thrifting of iridium by PEM electrode fabricators are in the range of one order of magnitude less metal than is currently needed, whilst being able to maintain efficiency.

The highly modular nature of PEM electrolyser designs, now and for the future, makes removal of spent iridium-coated membranes at the end of operational life (typically 10 years) relatively straightforward. This minimises downtime, though it does require additional stock of iridium catalyst to be held, to continue operations while the previous catalyst is recycled for use again. As electrolyser production scales up with the increasing automation of processes, less of the iridium-based catalyst is lost during assembly; most, but not all, could be recovered and recycled, though there are losses in recycling and, of course, additional iridium would need to be purchased to cover this inefficiency.

Demand

Current and future applications of iridium and demand trends

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Iridium demand is highly diversified, an attribute shared with most of the other PGMs.

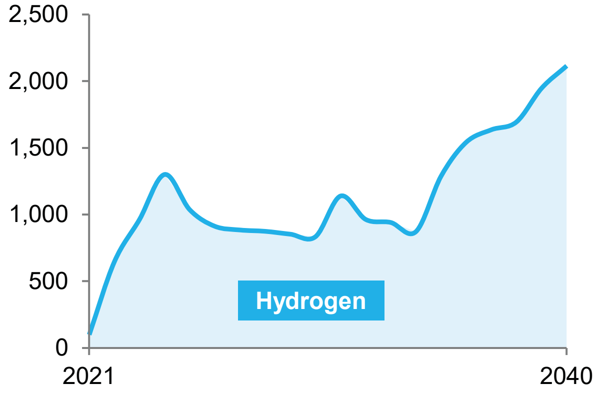
End-uses involve a mix between '***capacity***', where metal is used in tooling or as a catalyst in the manufacture of other products, and '***consumption***', where the metal goes into end-products.

The properties of iridium are hard to beat; the main demand areas and their contribution to the total are shown in the pie charts below, with use in the hydrogen sector starting to emerge, though currently still a small fraction of the whole.

Iridium demand is relatively 'sticky'; substantial CAPEX in complex processes based around the use of iridium discourages frequent swapping of materials, so once iridium is used it is unlikely to be substituted unless there is an entirely new process or new generation of product.

Iridium end-use forecast

Indexed,100=2021

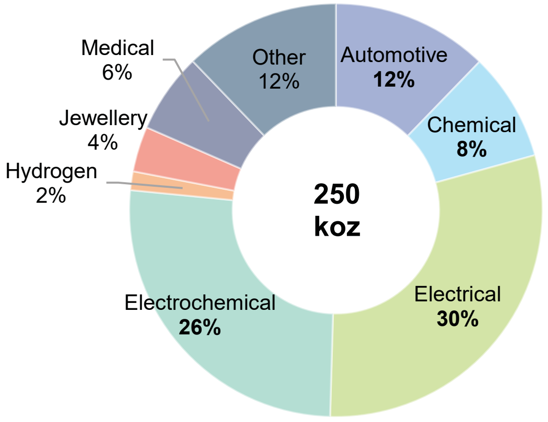


Source: SFA (Oxford)

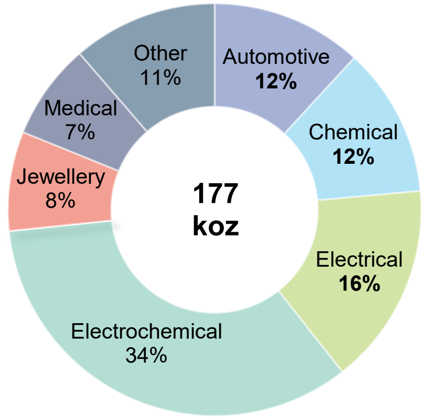
Capacity demand shows more volatile positive and negative growth rates, high during capacity installation but flat or negative for some years thereafter when only relatively low levels of top-up are required. Electrical and chemical are the main sectors of capacity demand. Electrochemical end-uses are characterised by gradual loss of the iridium-based coating during operating lifetime, with periodic re-coating or top-ups.

Consumption demand, where the iridium metal becomes part of the product, is seen mainly in automotive spark plugs, jewellery and biomedical devices. This tends to show steady growth, approximately in line with GDP. Material is largely open-loop recyclable.

Iridium demand: 2021

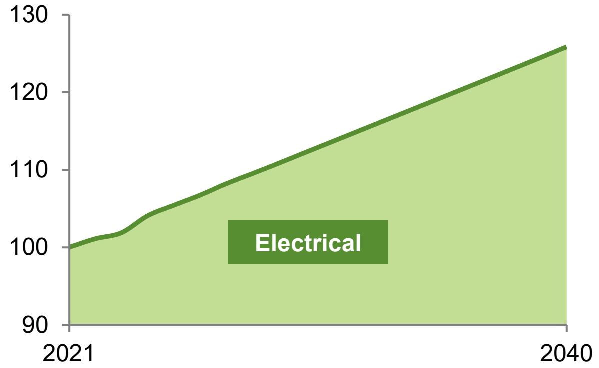


Iridium demand: 2012



Source: SFA (Oxford)

Iridium end-use forecast
Indexed,100=2021



Source: SFA (Oxford)

Iridium end-use forecast
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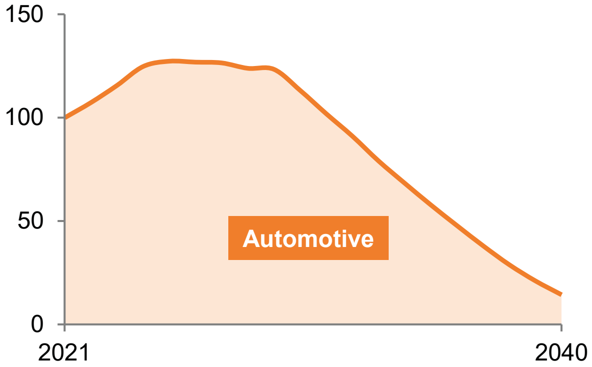


Source: SFA (Oxford)

Electrical: iridium is used for crucibles for melting oxide materials to make crystalline materials for electronics uses, as it is durable under high temperatures and harsh chemical conditions.

Its stability also means it does not contaminate the crystalline materials; very high purity is required to ensure the performance required of these materials. Closed-loop recycling is well established once crucibles become brittle and damaged, with relatively high collection and recovery rates, but continued demand for additional capacity drives growth. Some alternative crystal growth processes do not rely on crucibles at all.

Metal substitution opportunities are limited as crystal material quality cannot be compromised and if crucible durability is to be maintained, though there may be scope for some limited replacement of some iridium with some platinum. Technology substitution may be possible in the future if the materials made in iridium crucibles – lithium tantalate for surface acoustic wave (SAW) filters for frequency filtering in mobile devices and sapphire substrates for light-emitting diode manufacturing – are superseded by other technologies in these fast-developing electronic markets. In that case, a substantial return of iridium crucibles to the market could be seen, though it is possible novel materials may be developed which are optimally produced via iridium crucibles.

Electrochemical: iridium-coated anodes are widely used in a range of applications, including the chloralkali process, in water purification, in ballast water treatment and in electrowinning, where it confers high durability and catalytic activity in harsh environments.

Chlorine produced in the chloralkali process is a key global commodity chemical and the production of polyvinyl chloride (PVC) is the biggest global consumer of chlorine, while PVC, in turn, is the third most widely produced synthetic polymer. Today's membrane chloralkali process relies on high performance electrode structures and catalytic coatings, based on iridium and ruthenium coated on titanium or nickel, for lower energy inputs and higher durability than alternatives. Thus there is little scope for material substitution for iridium in these processes. Alternative products made via different synthesis routes may provide similar performing materials for some applications though, reducing some iridium demand. While PVC is currently the material of choice for many pipe applications since it is strong, lightweight, resistant to chemical corrosion, easy to assemble and recyclable, there are less cost-efficient alternatives such as HDPE which may be considered. Significant amounts of iridium are lost during the operating lifetimes of electrodes in many electrochemical processes, so recycling is limited.

Automotive: iridium is the metal most resistant to the destructive effects of heat and strongly oxidising environments. Iridium-tipped spark plugs, for gasoline vehicles and for industrial gas engines, offer more energy-efficient combustion, thus improving fuel economy and reducing emissions, plus their durability enables far less frequent replacement compared to plugs based on other metals for gasoline engines. Platinum is already widely used in gasoline vehicle spark plugs, so can readily replace iridium if required and ruthenium has some substitution potential too, while rhodium is also used in industrial spark plugs, but, like iridium, has episodes of high and volatile prices. Technology substitution out of spark plugs in gasoline vehicles will take place as battery electric vehicles increasingly displace the internal combustion engine over the decades ahead, driven by zero emissions legislation.

Industrial gas engines are less likely to see substitution; durability requirements mean that there is little alternative to iridium and the technology is expected to endure, indeed many of today's engines are designed for the future, to use hydrogen, partially or completely, instead of hydrocarbon fuels.

Recycling of vehicle spark plugs is open loop, with very low collection rates as the iridium content per plug is small, making the collection, separation and recovery economically unattractive for much of the industry. Higher rates of collection are sometimes seen. Recovery of process scrap is carried out. Collection and recycling of industrial spark plugs is mostly closed loop, but with significant operating and process losses.

Jewellery and medical: iridium is used mainly as a minor component with platinum in specialist alloys where it confers exceptional mechanical strength. In platinum jewellery, iridium is used in parts such as clasps/locks that are subject to high mechanical stress. Future demand for iridium is entirely dependent on the popularity of platinum jewellery, which currently appears to be in decline. Recycling of old jewellery is an open-loop process, but collection rates are low in most regions. Alloys of platinum and iridium are used in medical applications such as electrodes in pacemakers and electrophysiology. Open-loop recycling of used electrophysiology catheters is well established, especially from hospitals in the U.S. In both the jewellery and medical sectors, there will be some recycling of process waste.

Chemical: iridium is a well-established catalyst for the synthesis of acetic acid, a commodity for the chemical industry as a building block for many globally important polymers, including vinyl acetate monomer (VAM) and purified terephthalic acid (PTA). Iridium catalysts are cost-effective by enabling processes to run at higher conversions (producing higher volumes of high-quality product with no need for further purification steps) and with lower energy inputs.

Catalysts are closed-loop recycled efficiently, but with some top-up demand in addition to new capacity additions. VAM is used in the production of resins and polymers for a wide range of paints and speciality coatings. PTA is used for the production of polyester fibres and to produce polyethylene terephthalate (PET), widely used for bottles to replace heavier glass. While there is a growing requirement for these plastics, driving demand growth for PTA, there is conversely increasing demand for recycled PET, which will curb demand growth for new PET and hence for iridium catalyst.

As a planet, we have agreed that global warming must be contained: that means halving carbon emissions by 2030 and reaching a state of net zero – where the Earth absorbs as much carbon as mankind puts into it – by 2050.

There are many ways to achieve this, and it looks increasingly as if all of them have a part to play – there is no one single answer.

There is no need to wait any longer for new technologies, it is time now to implement and to scale up what is already developed and proven.

The green energy transition pivots on the concept of renewable molecules (hydrogen) generated from renewable electrons.

Green hydrogen is important as part of the pivot to net zero by decarbonising key sectors.

Hydrogen is an energy carrier – it is scalable and can be stored over long periods, making it particularly well-suited to getting the most out of intermittent renewable/low carbon energy (from wind, solar, hydro, even nuclear) then making it available to consumers, both industrial and domestic.

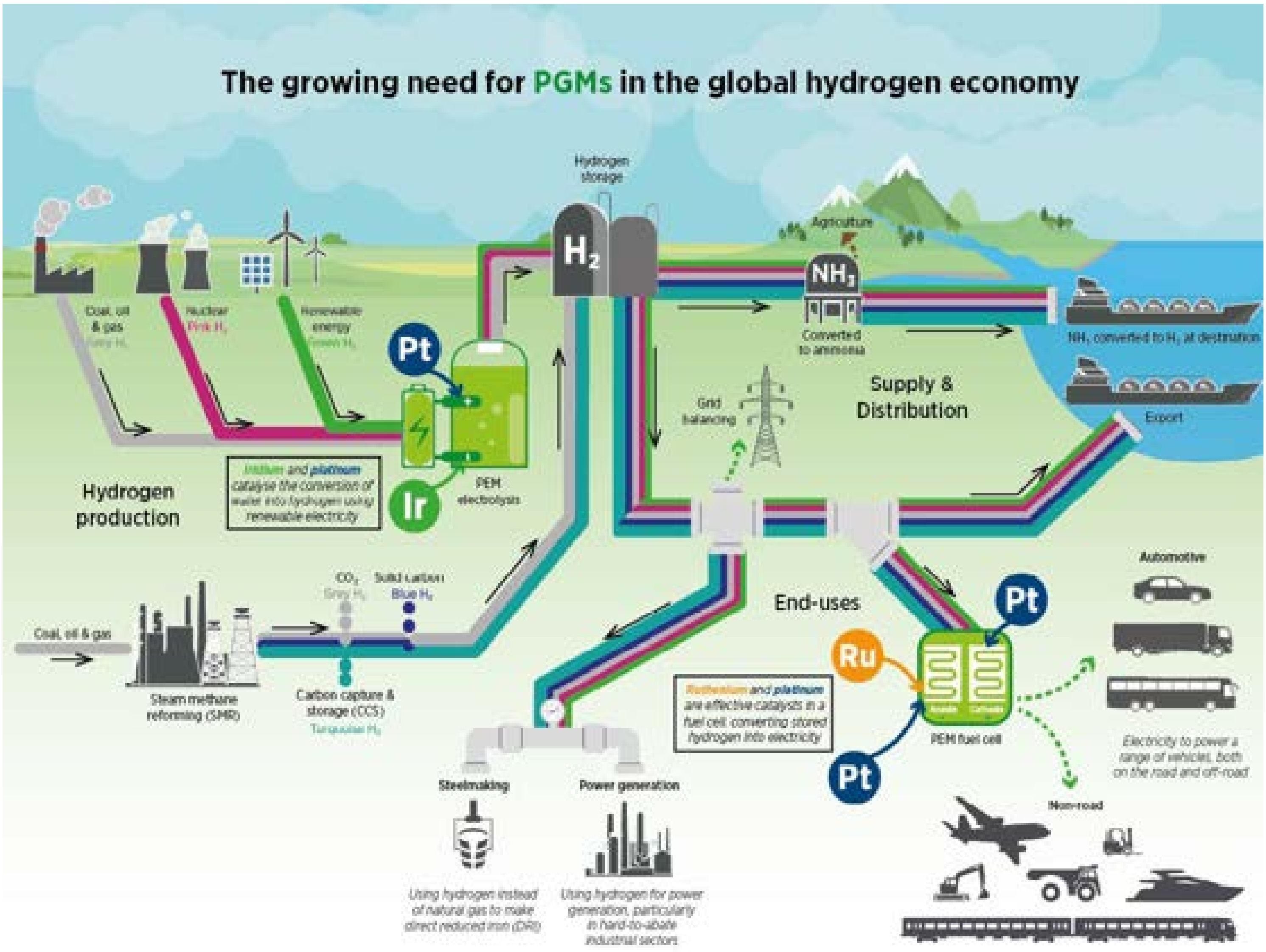
In industry, hydrogen is already established as a feedstock in vital sectors, including ammonia as a precursor for fertiliser to grow food crops, in methanol as the starting point for the synthesis of many industrial chemicals and in steel manufacturing.

For mobility, hydrogen and hydrogen-based fuels such as ammonia and methanol can deliver power to many classes of vehicle (heavy-duty road vehicles, passenger cars, trains, boats, planes...) via fuel cells and internal combustion engines.

Hydrogen for hard-to-abate applications: as the production capacity for green hydrogen will remain limited for many years, it will be important to prioritise deploying this precious green hydrogen in some of the highly energy-intensive applications and products/markets, and those which are hardest to decarbonise (abate).

Where do PGMs fit into the hydrogen ecosystem?

Iridium is key to water electrolysis, via PEM electrolysers, to produce green hydrogen. Platinum is key to both PEM electrolysers and PEM fuel cells. Ruthenium plays a part in PEM fuel cells, particularly where the feed hydrogen may be slightly impure. Ruthenium is increasingly of interest in PEM electrolyser catalysts, in combination with iridium. Previously, ruthenium-based catalysts were not sufficiently stable in the PEM electrolyser environment, but research activities are increasingly successful. Substituting some ruthenium in PEM electrolyser catalysts would relieve some of the pressure on iridium supply. The ammonia value chain is an important part of the hydrogen ecosystem too, as ammonia is a hydrogen-rich molecule which can readily be synthesised and cracked to store and release hydrogen. Ruthenium catalysts are increasingly promising for ammonia synthesis. Ammonia is an excellent hydrogen carrier, with a very well-established global shipping and handling infrastructure. Liquid organic hydrogen carriers (LOHCs) are being developed as an alternative to gas compression or conversion to ammonia for transporting hydrogen, and PGM catalysts show great promise in the hydrogenation-dehydrogenation reactions that underpin LOHC technologies.

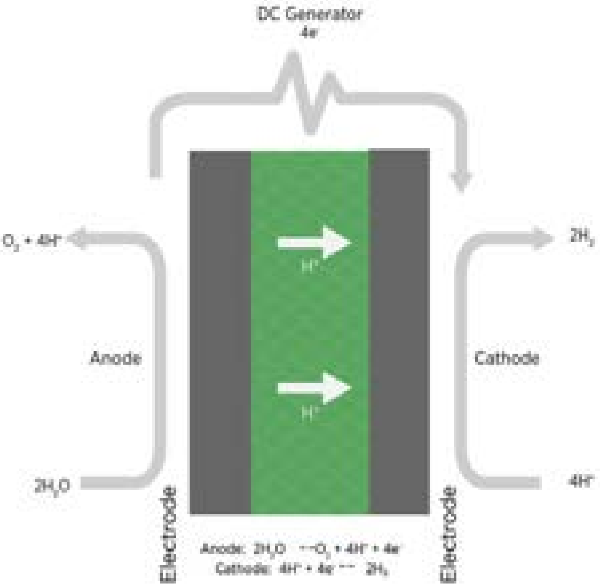

The growing need for **PGMs** in the global hydrogen economy

Source: SFA (Oxford)

Iridium plays a critical role in electrolysis, where water is split into useful hydrogen and oxygen.

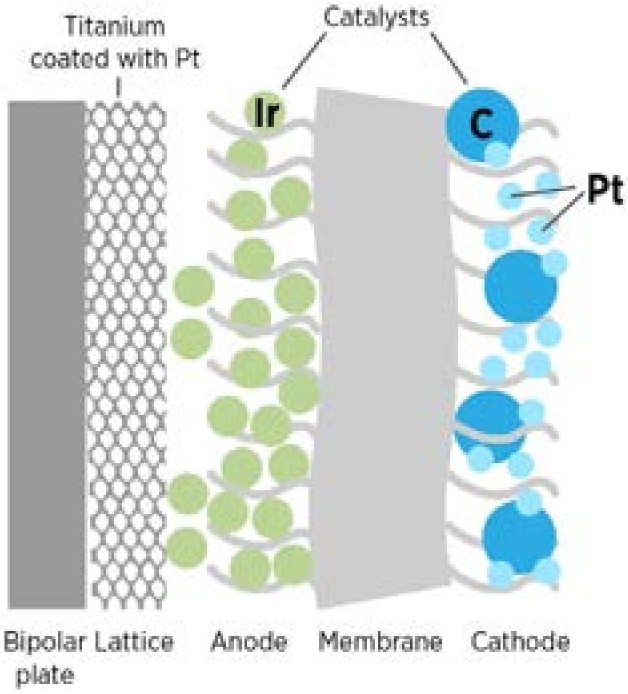
An electrolyser, simply, uses a cell with two electrodes separated by an electrolyte, which transports the generated charged species, the anions (-) or cations (+), from one electrode to the other. By applying an electric current through the water, it splits H_2O into its constituent elements of hydrogen (H), which is wanted as a fuel, and oxygen (O_2), which has value as an industrial and medical gas or can simply be released safely to the atmosphere. The diagram opposite summarises the process.

PEM electrolysis



Source: SFA (Oxford)

Cell-level



In a PEM electrolysis cell, the anode, the oxygen side, typically uses an iridium-based catalyst for the oxygen evolution reaction (OER), while the cathode, the hydrogen side, typically uses a platinum catalyst on carbon support. This is shown schematically to the left.

Iridium and platinum outperform the alternative catalysts which might appear cheaper or more abundant. The acidic environment, the high voltages, and oxygen evolution in the anode create a very harsh oxidative environment which very few other materials can withstand. Typically, titanium-based materials as the porous transport layer (PTL), and iridium and platinum which are superior catalysts and highly resilient, provide the best long-term stability and the best electron conductivity and cell efficiency. This is vital as, to be viable on an industrial scale, these electrolysers need to perform to specification for around 10 years, with no drop-off in performance.

Iridium oxide is regarded as the optimal catalyst for the OER in PEM water electrolysis. Ruthenium oxide actually has the highest activity for the OER among the single-transition oxides, but it is not sufficiently stable/durable under electrolyser operating conditions. Iridium oxide is slightly less active but has usefully higher corrosion resistance.

Currently, no complete substitution options exist for iridium in PEM electrolysis. It is the best material for the OER, preferred over the other PGMs (platinum or ruthenium) for its higher corrosion resistance and catalytic properties.

There are, however, several routes to reducing the iridium loadings in PEM electrolysers, which will be vital to the sustainable growth of green hydrogen production.

Binary or multi-metallic oxides of iridium combined with ruthenium can exhibit improved activity and stability compared to either metal alone.

Developing very high surface area supports is common in catalyst applications, where the catalyst is dispersed to maximise the active surface area available for the reaction.

The catalyst support is far from just a passive part of the structure and can be optimised to enhance overall performance. The support must be highly electronically conductive in acid environments at high potential, with a pore structure that enables a sufficient flow of reactants and products to and from the active site of the catalyst.

Novel catalyst structures and preparation routes, in particular core-shell structures and thin films, also show considerable promise for maximising catalytic activity from a given mass of catalyst metal.

At the system level of a PEM electrolyser, increasing the current density will reduce the amount of active material – in this case, iridium – needed per unit of hydrogen production capacity.

Supply

Strongly controlled by geography, iridium is mainly a South African product

3

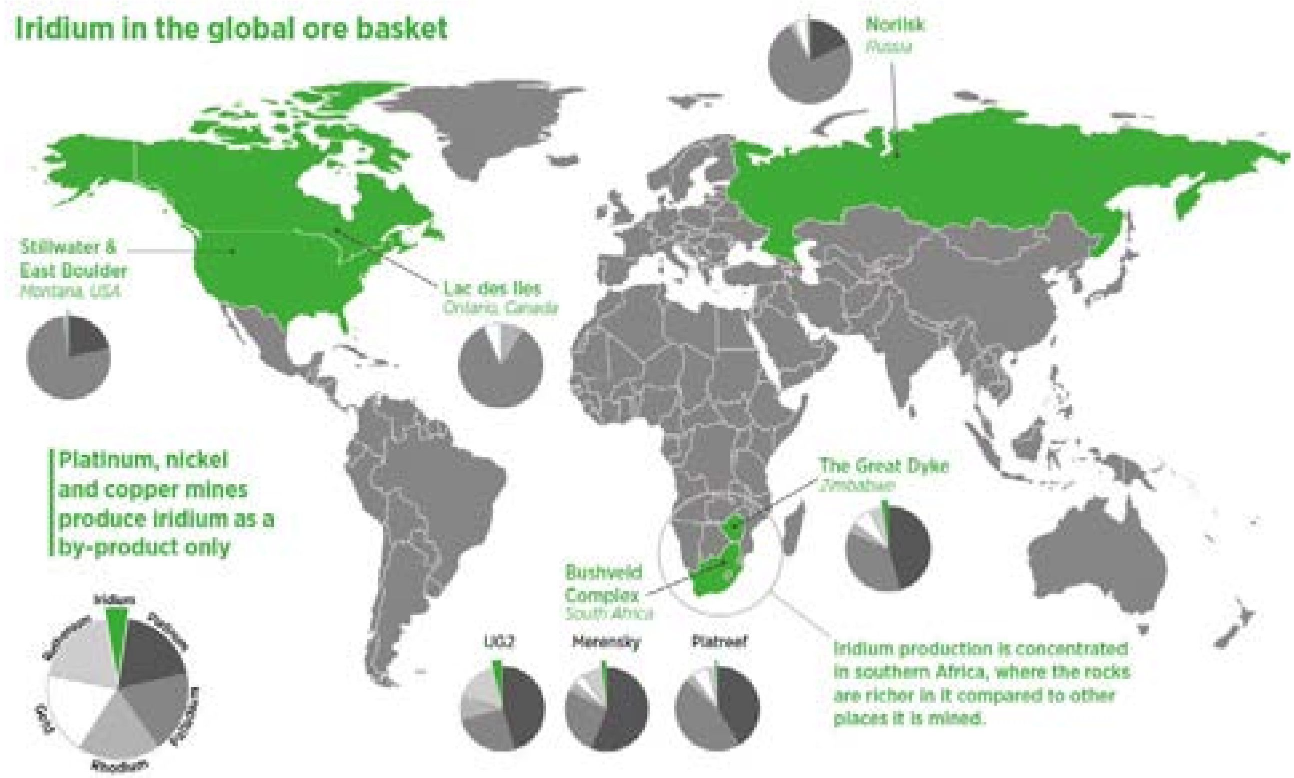
South Africa is the world's largest supplier of one of the key metals for the hydrogen economy, with over 80% of annual iridium mine supply.

South Africa's Bushveld Igneous Complex is the world's largest known resource base of the catalyst metals for hydrogen production and use, with three main PGM-bearing reefs – UG2, Merensky and Platreef.

Iridium is a by-product of mining for the full suite of the platinum-group metals (PGMs) which comprises platinum, palladium, rhodium, ruthenium and iridium.

For many years, iridium was of little interest to the major PGM producers and only in recent years have producers even begun reporting production volumes.

Small amounts of iridium are also recovered, again as by-products, from primary nickel and copper mining and from reprocessing PGM-containing chrome mine tailings.



Iridium in the global ore basket

Platinum, nickel and copper mines produce iridium as a by-product only

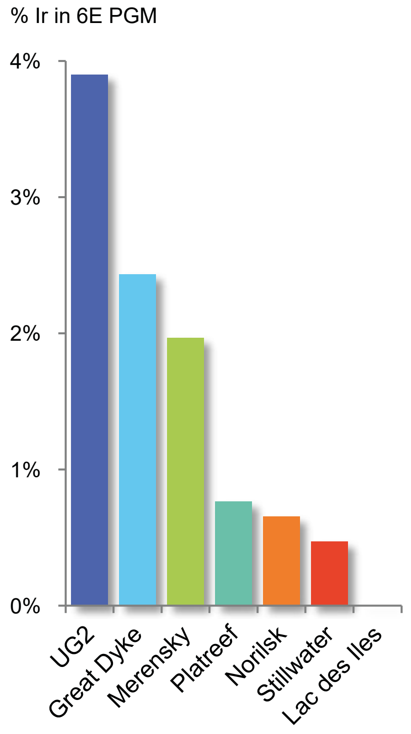
Iridium production is concentrated in southern Africa, where the rocks are richer in it compared to other places it is mined.

Source: SFA (Oxford)

Historically, this lack of transparency was something of a deterrent for end-users to confidently adopt iridium, despite the considerable stocks that producers held a decade ago. Adoption was also curtailed by the small size of these markets, particularly for iridium, which is by far the smallest of all the PGM markets; annual iridium production has reached around 250 koz, shown in the chart below, and is less than one-twentieth the size of the 6,000 koz platinum production per annum.

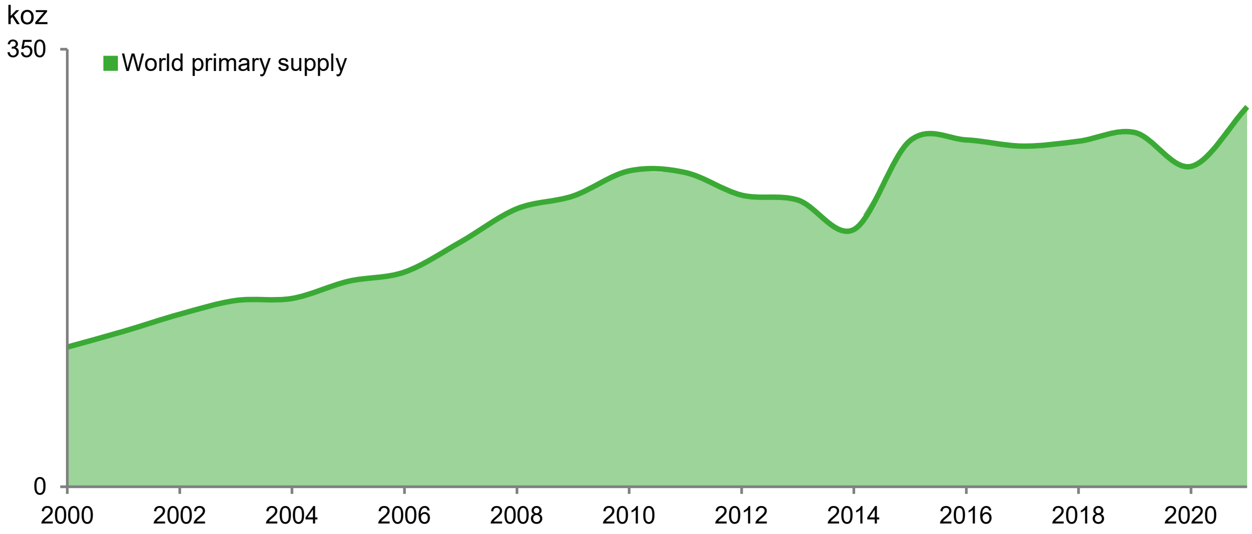
For mined iridium supply to be available for future hydrogen applications, it will be vital for substantial markets to continue for the other PGMs to sustain revenues and incentivise investment in future supply. Iridium's contribution to mine revenue is inevitably small since it comprises less than 4% of contained PGM grade in orebodies worldwide, shown in the bar chart to the right. Of course, it is expected that platinum will be used in fuel cells and in electrolysers alongside iridium.

Iridium share of contained PGM grade by orebody



Source: SFA (Oxford)

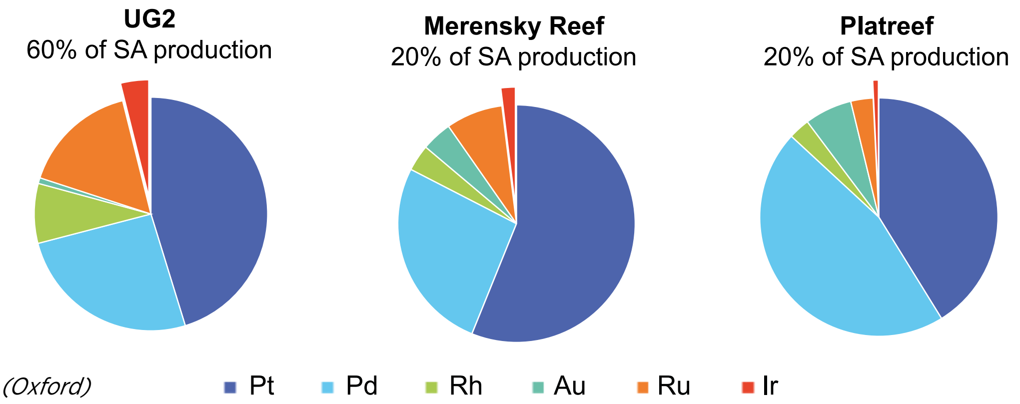
Global Ir production



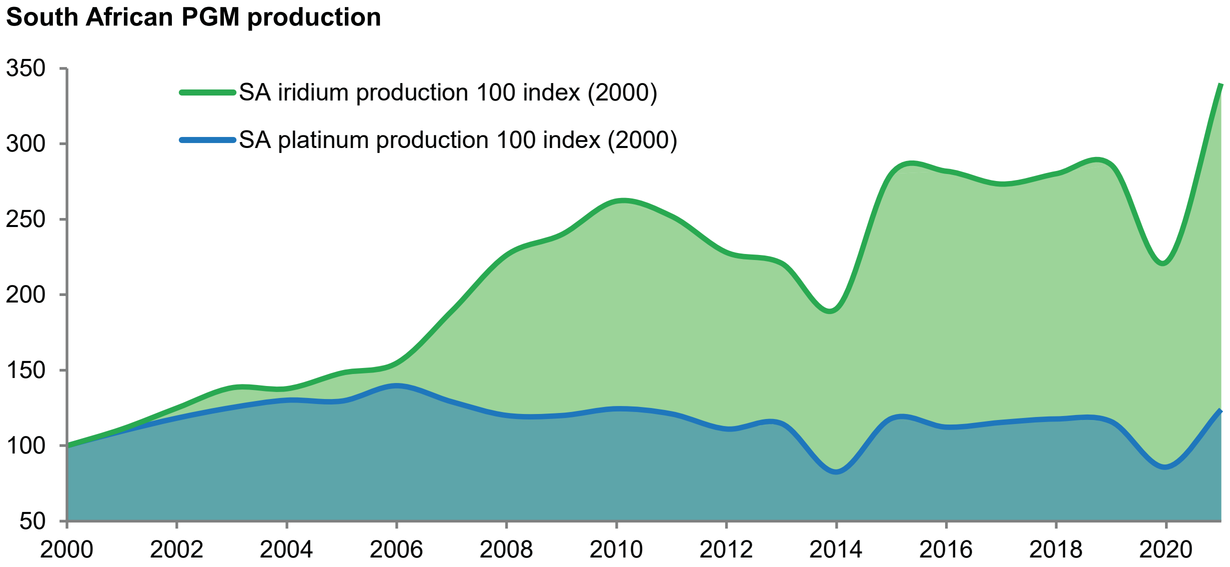
Source: SFA (Oxford)

Since the mid-2000s, South African producers have increasingly focused on the extraction of ore from the UG2 Reef, as older Merensky operations deplete and newer generation shafts become deeper (higher cost). The Merensky orebody was previously preferentially mined owing to its typically superior grade, high platinum content and comparatively high base metal content which aid metal recovery. The UG2 orebody, which is now ~60% of all South Africa PGM mining (more than double volumes in 2000) contains, on average, ~3% Ir (of total 6E PGM production) which is a greater concentration than the Merensky Reef (~2%) and far higher than Platreef (<1%).

Consequently, the PGM production mix is gradually shifting closer towards the metals required for the hydrogen economy, as the UG2 Reef prill split is much more weighted towards iridium (up to 3.3%) and ruthenium (up to ~13%) than any other PGM orebody worldwide. The index chart below shows how, since the year 2000, growth in South African iridium production has substantially outpaced that of platinum production.



Source: SFA (Oxford)



Source: SFA (Oxford)

Supply Chain

From mine to market and recycling

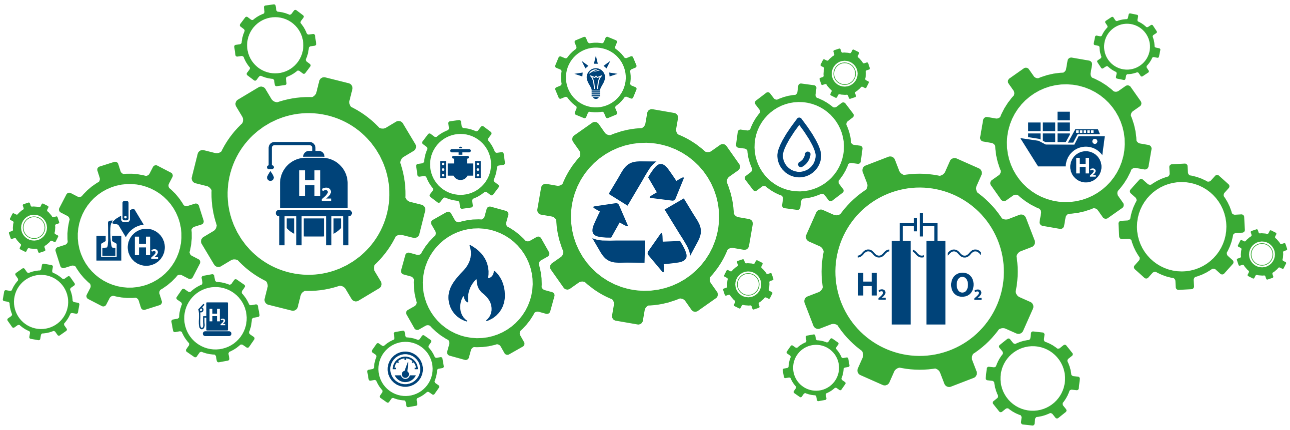
4

Recycling the iridium from PEM electrolysers will be vital to ensure continued availability of this scarce metal...

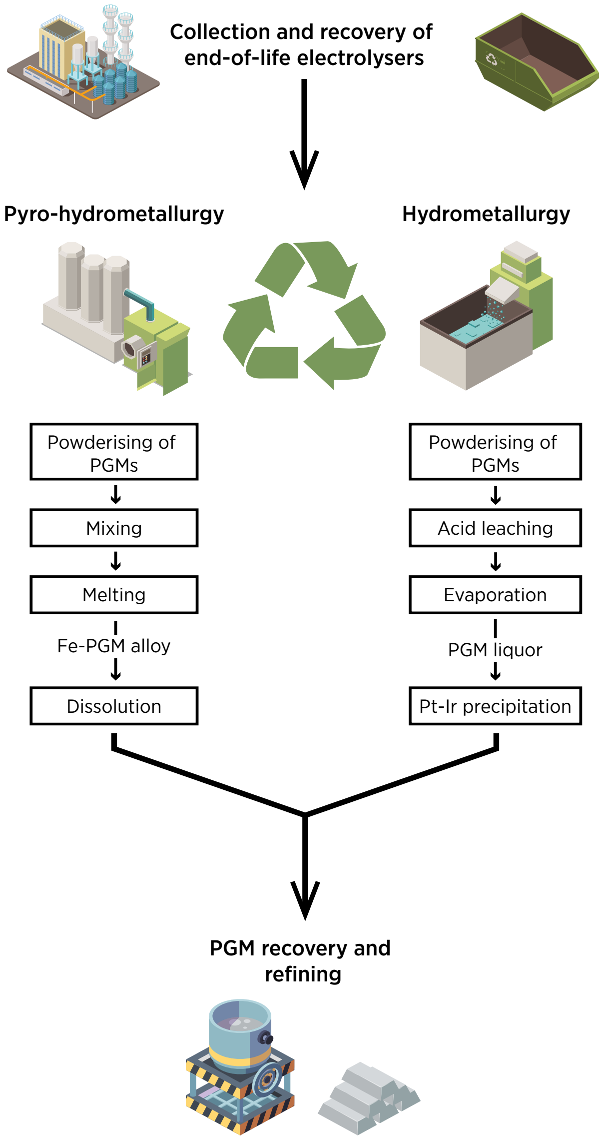
...but also for the wider environmental sustainability of the entire product components and manufacturing process.

Collection of end-of-life electrolysers should be relatively straightforward, as these are high-value items located with industrial customers. Most PEM electrolyser manufacturers currently design for a 7-10-year stack operating lifetime.

Recycling some of the other high-value materials, including titanium, steel and fluoropolymers, will add to the motivation for collection and recovery. Particular care must be taken to ensure that the processing and recycling of the membrane, typically made of polyfluorinated alkyl substances (PFAS), is completed without release of any of the contained fluorine, which is harmful. Combustion processes have been favoured to remove the membrane, leaving behind the iridium-rich residue for further processing steps through pure metal and back to an iridium salt, the form in which it is used for applying to a new membrane for a new product.



Potential metal recovery and recycling process for PEM electrolysers



Source: SFA (Oxford)

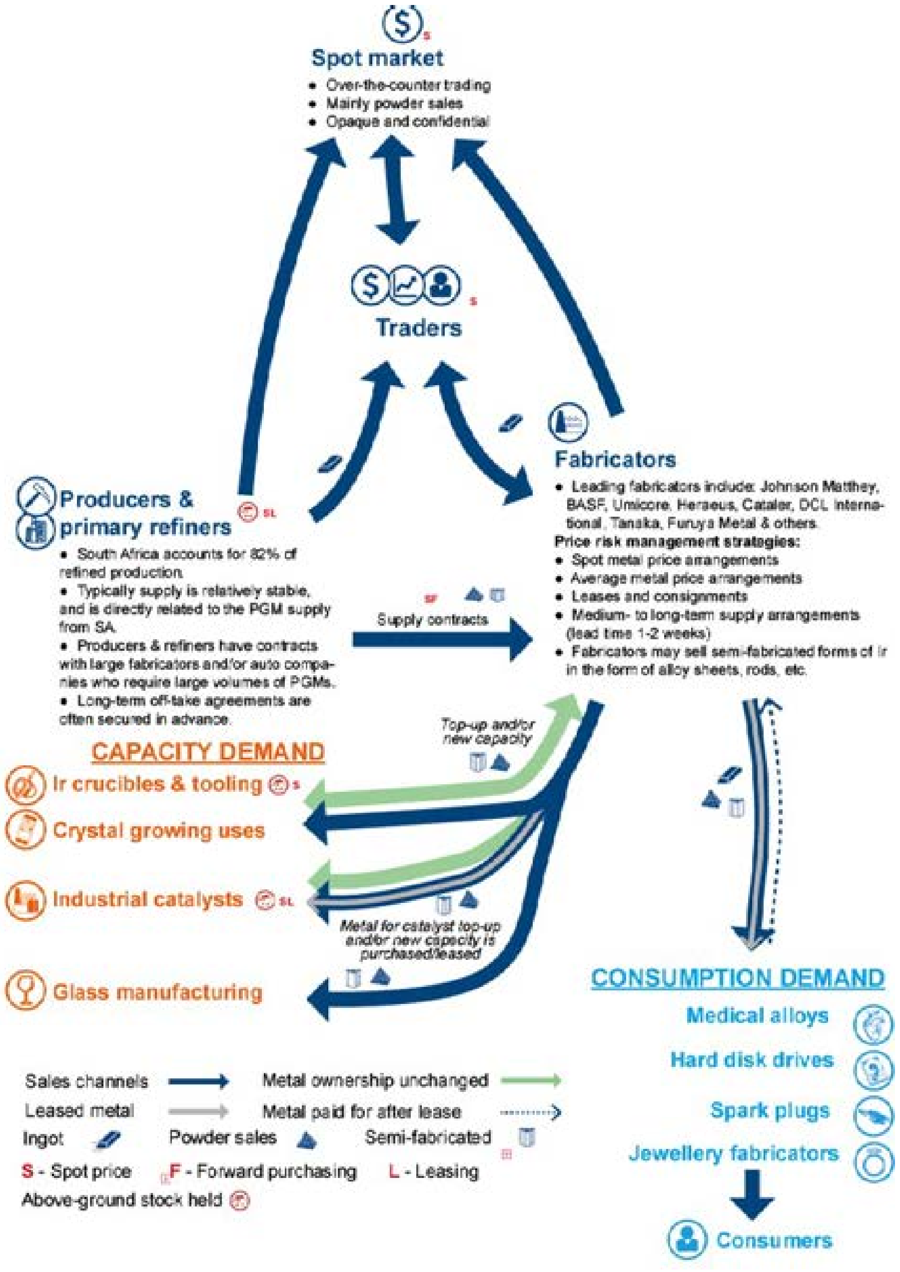
Recovery of iridium (and platinum) from PEM electrolysers is based on processes which are well-established in the PGM sector, namely hydrometallurgical and pyro-hydrometallurgical recoveries. Hydrometallurgical treatment is highly selective to the metals and has reasonably low energy consumption but requires mechanical pre-treatment of the waste material to maximise the surface area and hence to maximise PGM recovery. Pyro-hydrometallurgical treatment can deliver higher recovery efficiency but requires higher energy input. The BEST4Hy project, which receives funding from the European Union through the Clean Hydrogen Partnership, continues to investigate the recycling of PEM electrolyser materials.

Logistics and accounting factors will play an important part along with these technical issues in determining the long-term sustainability and success of this market. Iridium will be embedded within an electrolyser for over a decade; while similar to the use of platinum, palladium and rhodium in autocatalysts, the much smaller volume of the iridium market raises some new issues. The long timespan of a PEM electrolyser – from initial placement of order, long lead time, through product build, operating lifetime, collection of spent material, to reprocessing to material ready to make catalyst for a new electrolyser – means that significant capital is tied up. Movement of PGMs and PGM-based chemical products across national and continental boundaries is not always straightforward (affecting China in particular), with the possibility of bans, delays and high taxes further impeding the flow of iridium for the electrolyser market.

Nature of Iridium Trading

Stocks and flows in an opaque market

5



Spot market

- Over-the-counter trading
- Mainly powder sales
- Opaque and confidential

Producers & primary refiners

- South Africa accounts for 82% of refined production.
- Typically supply is relatively stable, and is directly related to the PGM supply from SA.
- Producers & refiners have contracts with large fabricators and/or auto companies who require large volumes of PGMs.
- Long-term off-take agreements are often secured in advance.

Fabricators

- Leading fabricators include: Johnson Matthey, BASF, Umicore, Heraeus, Cataler, DCL International, Tanaka, Furuya Metal & others.

Price risk management strategies:

- Spot metal price arrangements
- Average metal price arrangements
- Leases and consignments
- Medium- to long-term supply arrangements (lead time 1-2 weeks)
- Fabricators may sell semi-fabricated forms of Ir in the form of alloy sheets, rods, etc.

Source: SFA (Oxford)

Iridium trade flows are opaque with little access to those outside of trades.

Sales and trading strategies are very different as the iridium market (250-300 koz p.a.) is so much smaller compared to platinum (~6,000 koz p.a.) and the other PGMs. The iridium market is illiquid, it is not a terminal market, and sales are made off exchange. Stocks of partially refined iridium are understood to have been built up some years ago by some of the producers, when demand was relatively low, but these are largely exhausted as demand has outpaced mined supply over recent years.

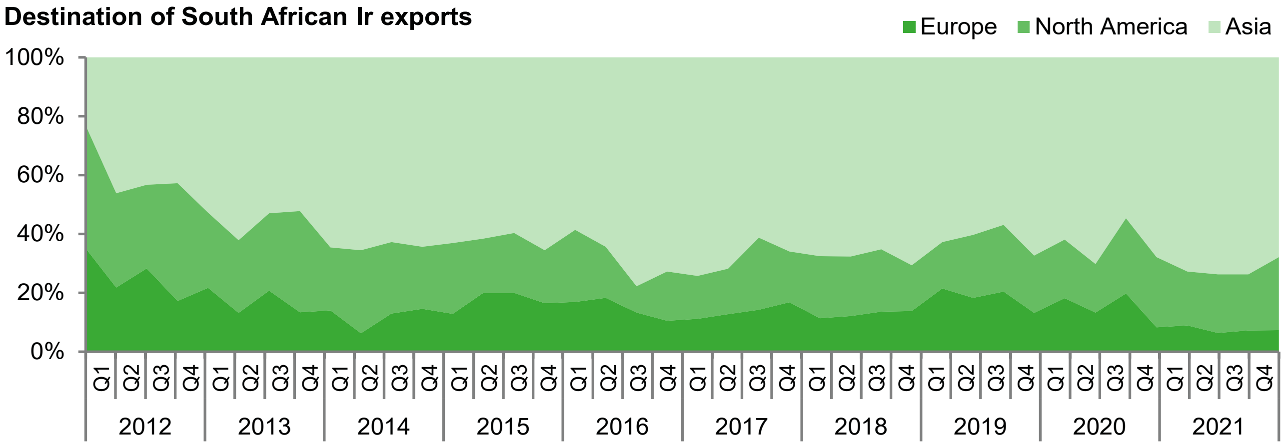
Industrial users tend to be active purchasers in the market, closely following price trends and typically buying metal to meet several months of their production needs when they perceive prices to be low. Overall trading volumes can be very small over many weeks, so when a large trade is made, that can move the price and prices are generally more volatile than those of the larger PGMs.

Opportunities to invest in iridium are minimal, with no room for speculators in this market. There are no investment products in iridium such as ETFs which are widely used by investors in platinum and palladium, which are much larger markets. It has emerged recently that there has been some opportunistic purchasing of iridium, beyond that required for industrial needs, by sophisticated investors as interest grows in the long-term potential of iridium for hydrogen production.

Exports into the EU typically form a small portion of South Africa's total iridium exports, summarised by quarter in the chart below. There is considerable variation between each period, due to a combination of varying shipment sizes but also data collection and reporting factors.

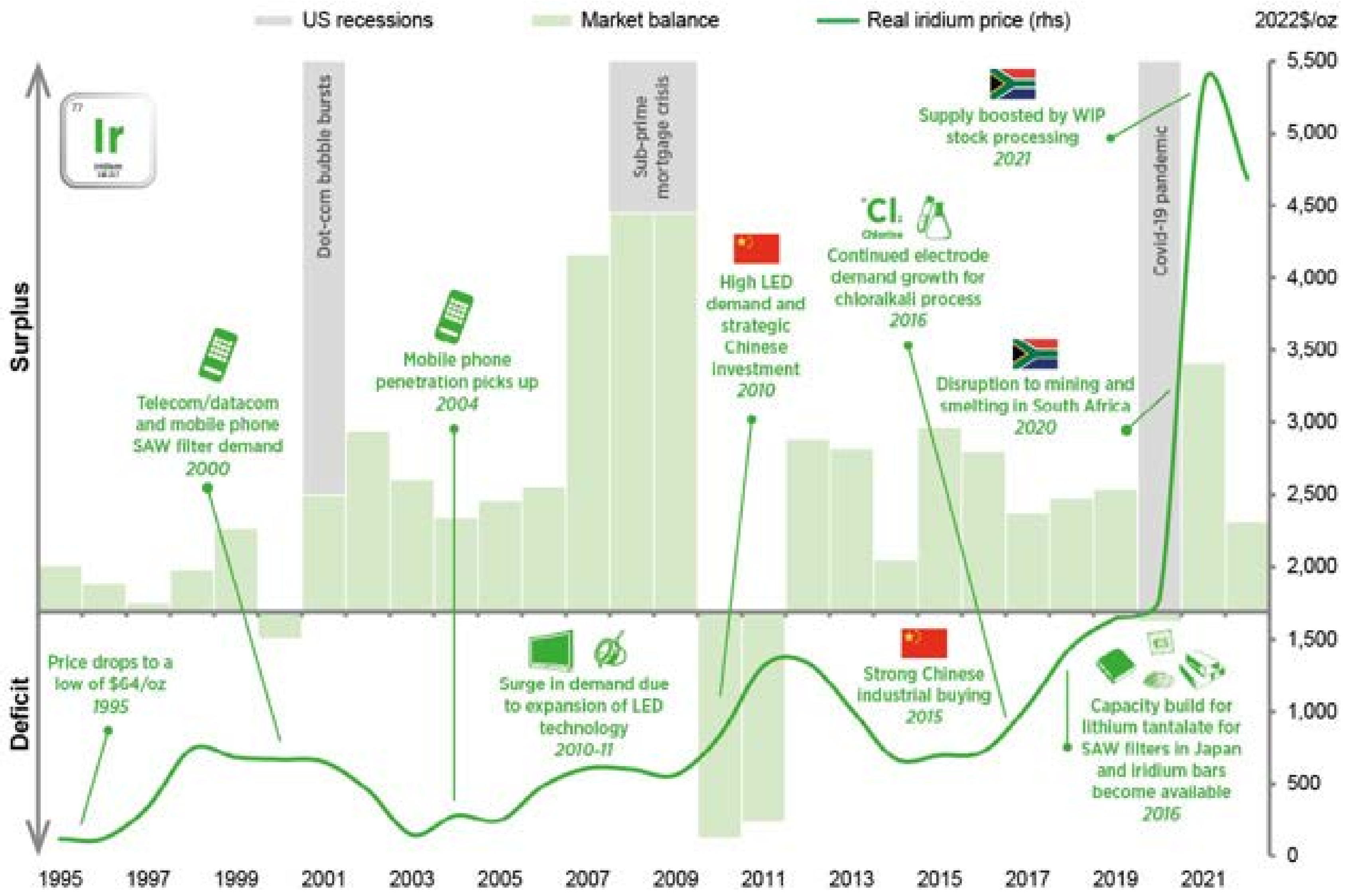
Iridium export volumes can reveal temporary problems with metal availability, such as those experienced during 2020, when air freight out of South Africa was curtailed due to the pandemic and when some smelter issues disrupted metal output.

Caution must be exercised when analysing trade data as South Africa does not separate iridium and ruthenium, so exports are calculated using relative production. There is also the risk of double counting metal. When metal undergoes a value-added procedure in one country then is exported to another for final manufacturing or re-processing, the metal will be counted again as volume exported/imported. Thus, the apparent global volume of metal traded is inflated above actual stocks.



Source: SFA (Oxford), Trade Data Monitor

Historical iridium market balance



Total supply	233	229	206	277	277	272	276	283	231	332	303
Total demand	177	176	189	217	225	240	239	243	235	252	278
Price, rhs		825	555	562	594	896	1,283	1,480	1,629	5,075	4,655

Source: SFA (Oxford)

GLOSSARY OF TERMS

CAPEX
Capital expenditure.

Chloralkali process
The industrial process for the electrolysis of sodium chloride solutions.

Closed-loop recycling
Recyling a product into the same product with minimal loss of material.

Electrowinning
A process by which metals are recovered from a solution by means of electrolytic chemical reaction.

GDP
Gross domestic product.

Great Dyke, The
A PGM-bearing linear geological feature that trends nearly north-south through the centre of Zimbabwe passing just to the west of the capital, Harare.

Gross demand
A measure of intensity of use.

GW
Gigawatt.

koz
A thousand troy ounces.

Merensky Reef
A PGM-bearing horizon within the Bushveld Igneous Complex, South Africa. Also contains nickel and copper sulphides that are mined as by-products.

moz
A million troy ounces.

Net demand
A measure of the theoretical requirement for new metal, i.e. net of recycling.

Net supply
Proxy supply of metal surplus to requirements.

Open-loop recycling
Recycling products from one or many sources into a different product.

oz
Troy ounce.

PGM
Platinum-group metals.

Platreef
A PGM-bearing orebody mineralogically similar to the Merensky Reef, but that lies at the footwall of the Northern Limb of the Bushveld Igneous Complex.

Prill split
The proportion of metals in a given ore.

Primary supply
Mine production.

Secondary supply
Recycling output.

Thrifting
Using less metal in order to reduce costs.

UG2 Reef
A PGM-bearing horizon within the Bushveld Igneous Complex, located stratigraphically below the Merensky Reef. Typically comprises higher iridium and lower base metals contents than the Merensky Reef.

6E
Platinum, palladium, rhodium, gold, ruthenium and iridium.

Currency symbols:

$ US dollar.

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