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ENHANCING SUSTAINABILITY OF OUR GLOBAL PLATINUM GROUP METAL (PGM) SUPPLY

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Goals of Cooperative U.S. – Europe PGM Program (USEPGM)

- **Analysis of the value chain for primary and secondary sources of PGM**
- **Identification of bottlenecks limiting PGM production and recovery**
- **Proposal of joint research and development as well as innovation tracts to fix identified bottlenecks**
- **Work jointly to promote identified issues to the public, policy makers, and industrial organizations**

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Topics of Interest to USEPGM Collaborators

- **Status of global PGM occurrence and use from primary and secondary sources**
- **Future prospects for application of PGM in new technologies where their unique physical and chemical properties are essential**
- **Limitations of conventional separation and recovery processes in conventional metallurgical operations**
- **Challenges facing the PGM mining industry: dwindling ore grades, geo-political issues, and increasing environmental concerns as waste production increases and electricity demand expands with attendant increased coal combustion**
- **Why less than half of PGM mined is recovered from spent secondary resources**
- **How new technologies and approaches can significantly improve PGM recovery rates, especially from spent products containing PGM in small amounts**

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Status of PGM Recovery: Major Secondary Sources

- **Major industrial uses of PGM are in autocatalytic converters in vehicles Pt (40%), Pd (69%), Rh (95%) and in petrochemical catalysts**

- **Recovery rate >95% for PGM where collected items can be treated in integrated smelters**

- **<u>Bottlenecks:</u> few integrated smelters worldwide; transportation cost of collected items to smelters usually prohibitive due to distance**

- **<u>Result:</u> global recovery of PGM from these spent products about 50%, remaining PGM usually discarded to landfill with product**

- **<u>Need:</u> increase capacity to recover PGM at or near site of generation, possibly with mobile, modular separation units**

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Status of PGM Recovery: Minor Secondary Sources

- **Discarded spent electronic and electrical equipment, plating baths, decorative applications and others total ~50 million tons/year globally and increasing**
- **PGM usually present in each unit in low amounts, ppm or less**
- **Traditional separation technologies –ion exchange, solvent extraction, precipitation – not economic for PGM recovery at low concentration levels**
- **<u>Bottlenecks</u>: collection of spent items, transport to integrated smelters, inadequacy of traditional separation technologies to make economic PGM recoveries possible**
- **<u>Result</u>: estimated 5% or less recovery of PGM globally with remainder discarded with product as waste**
- **<u>Need</u>: technologies capable of making separations and recovery at low concentration levels; mobile recovery units, probably hydrometallurgical, that can economically recover PGM at or near site of waste generation**

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Bottlenecks in Pyrometallurgical Processes for PGM Recovery

- **Few integrated smelters globally**
- **Specialized equipment needed to prevent emission of dioxins and other chemicals**
- **High energy input**
- **Long inventory time for PGM**
- **Incomplete recovery of PGM**
- **High cost to dispose of ash, slag, and other components**

Iannicelli-Zubiani, E.M., et al. 2017, *J. Clean. Product.* 140, 1204-1216

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Bottlenecks in Traditional Hydrometallurgical Processes for PGM Separation and Recovery – SX, IX, Precipitation

- **Series of acidic or caustic leaching steps of solid material required**
- **Low selectivity for individual PGM, many process steps, complex flow sheets**
- **Organic solvents and sizeable amounts of chemicals used for PGM extraction**
- **Low ability to concentrate target PGM from dilute solutions**
- **Generation of large amounts of waste**
- **High capex and opex costs**

Iannicelli-Zubiani, E.M., et al. 2017, *J. Clean. Product.* 140, 1204-1216; Izatt, R.M., et al. 2015, *Green Chem.*, 17, 2236-2245.

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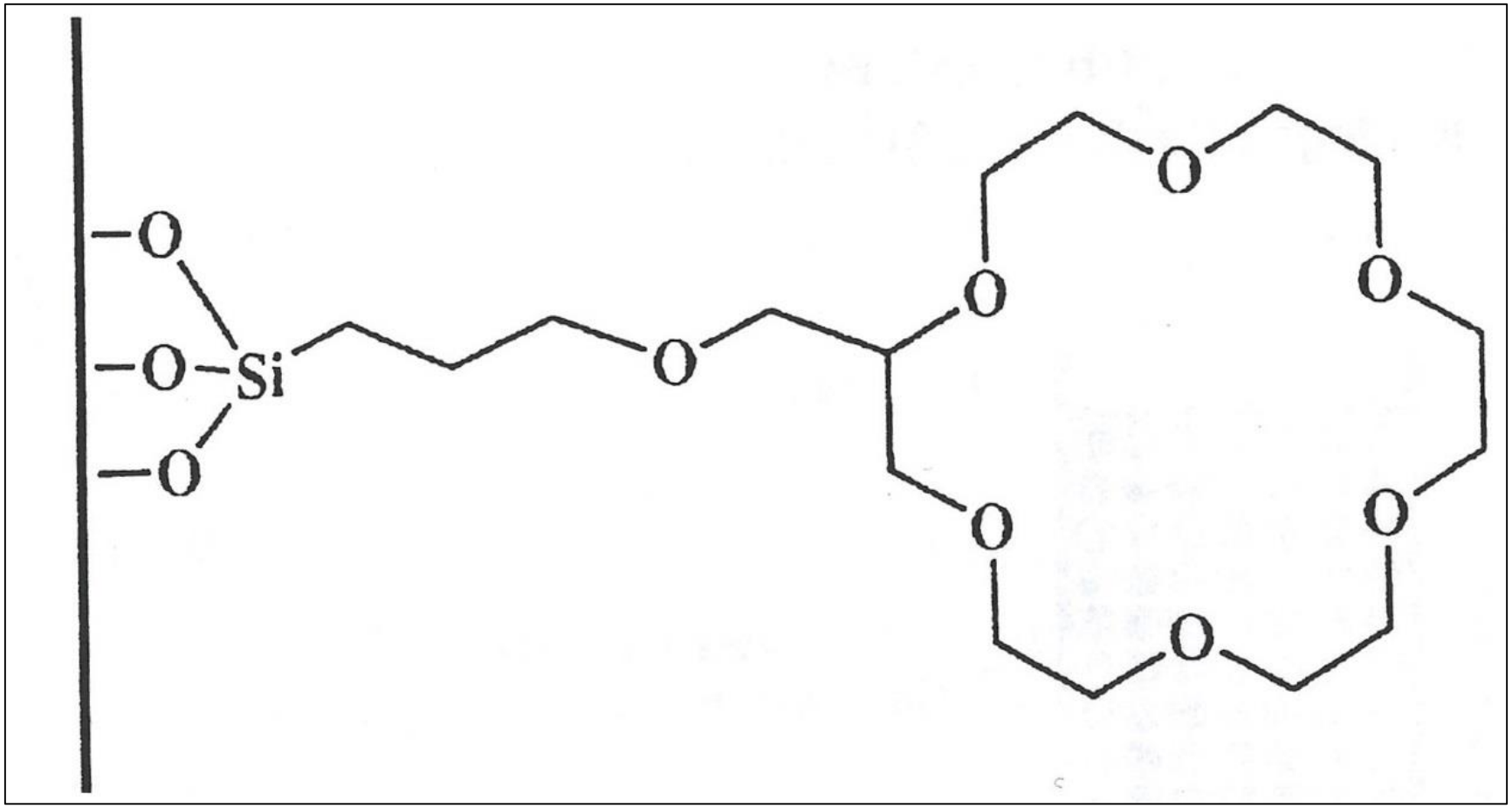
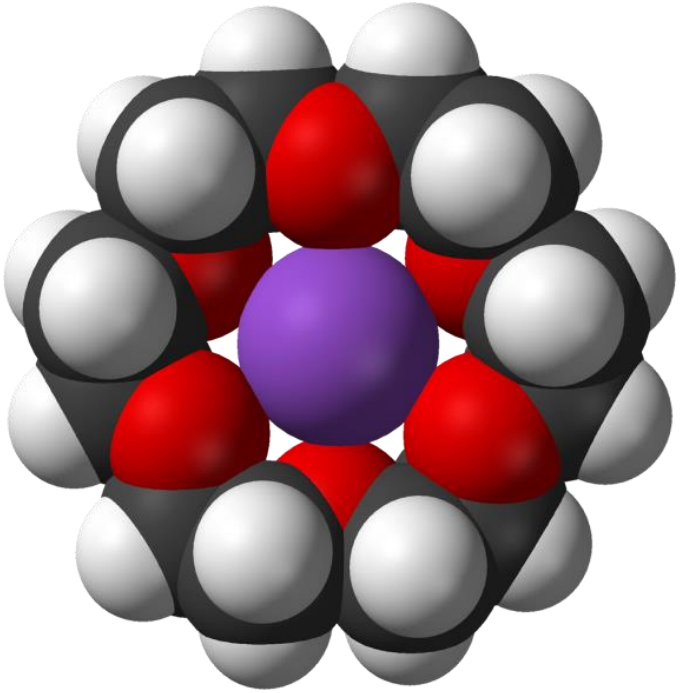
How SuperLig® - MRT Processes Work – SuperLig® Product



Izatt, R.M., et al. 2015, *Green Chem.*, 17, 2236-2245

How SuperLig® - MRT Processes Work – Metal Selectivity

Sodium ion Binding Affinity = 20,893



Cesium Ion Binding Affinity = 61,660

Potassium ion complex of 18-Crown-6
Binding Affinity = 1,258,925

Izatt, R.M., et al. 2015, *Green Chem.*, 17, 2236-2245

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How SuperLig® - MRT Processes Work – System Cycle Operation

- ***Loading phase*—target metal ion loaded from feed onto SuperLig® product charged into column(s)**
- ***Pre-elution wash phase*—remaining feed solution washed from column**
- ***Elution phase*—target metal ion eluted with small amount of eluent to form concentrated metal product**
- ***Post-elution wash phase*—remaining eluent washed from column. Cycle begins again with first step**
- **Small elution volumes give concentrated eluate solutions**
- **Regenerated resin can be used repeatedly**

Izatt, R.M., et al. 2015, *Green Chem.*, 17, 2236-2245

SuperLig® - MRT Systems can Overcome Several Bottlenecks in PGM Separations and Recovery

- **Simplification of separation system flow sheets minimizes waste production, minimizes energy and water usage, reduces separation costs, minimizes PGM loss, and minimizes PGM inventory time**
- **Recovery of individual PGM at low concentrations from waste solutions**
- **Modular SuperLig® - MRT systems can recover Pd at remote locations**
- **SuperLig® - MRT systems reused repeatedly in cyclic operation**
- **Incorporation of SuperLig® - MRT systems into integrated smelter refineries simplifies system flow sheets and minimizes waste generation**

Izatt, R.M., et al. 2015, *Green Chem.*, 17, 2236-2245; Izatt, S.R., et al. 2016, in *Metal Sustainability: Global Challenges, Consequences, and Prospects*, Izatt, R.M. (Ed.), Wiley, Oxford, U.K., pp. 317-332.

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Separation, Recovery and Purification of Individual PGM from Various Matrices using SuperLig® - MRT Products

- **Platinum** Pt from spent automotive catalysts
  Pt from Pt/Cr/Co/Cu alloy from the sputtering process

- **Palladium** Pd from spent automotive catalysts & mine feed
  Pd from spent petrochemical catalysts
  Pd from dipping bath solutions
  Pd from plating baths

- **Rhodium** Rh from spent automotive catalysts

- **Ruthenium** Ru from Ru alloy scrap

- **Iridium** Ir from solutions with matrices of base metals, Pd, Pt, Rh

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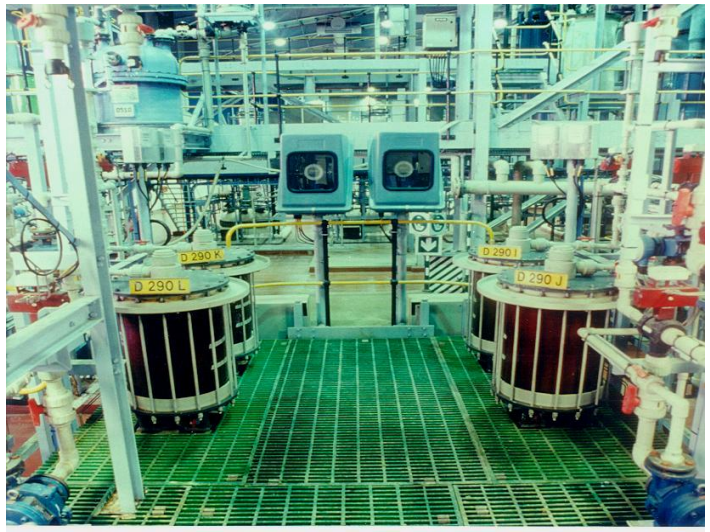
Platinum Group Metals (PGM)



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Examples of SuperLig® - MRT Industrial Processes

PGM Mining

Bottleneck: Many steps required to remove traces of Pd downstream in traditional PGM flowsheet; SuperLig® - MRT process selectively removed all Pd from initial PGM feed eliminating bottleneck

Result: Simplification of PGM recovery process, elimination of many steps, significant reduction of PGM inventory

Secondary PGM Refining

Bottleneck: Many steps required to separate Rh from other PGM in traditional flowsheet; SuperLig® - MRT process selectively removed Rh from initial PGM feed eliminating bottleneck

Result: Significant reduction in process time for Rh recovery; reduced floor space; minimized Rh inventory time; minimization of waste generation

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SuperLig® 277 unit for Pd separation and recovery from plating baths

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SuperLig®- MRT Modular Process for Palladium Recovery

Bottleneck: Pd recovery from spent plating-on-plastics drag-out bath not economic using traditional separation processes. SuperLig® - MRT process allows separation and recovery from spent plating baths using a modular unit which is sent to a central location where Pd is retrieved and unit is recharged before return to customer for reloading.

Result: Pd, present at approximately 1 mg/L is selectively recovered and saved from discard. Process works in-line with >95% Pd recovery and many process and environmental benefits resulting in cost savings to the customer

Izatt, S.R., et al. 2017. Recovery from Low Grade Resources of Platinum Group Metals and Gold Using Molecular Recognition Technology (MRT), IPMI 41st Annual Conference, Orlando, Florida, June 10-13.

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Economic Comparison of SuperLig® - MRT and Traditional Separation Technologies

- **High selectivity for individual PGM makes simpler systems possible with SuperLig® - MRT products reducing capital costs**

- **Non-use of solvents and minimal use of chemicals in SuperLig® - MRT systems avoid a host of complications that increase operation costs using Traditional Separation Technologies**

- **PGM inventories are much lower for SuperLig® - MRT systems due to rapid processing times**

Izatt, S.R., et al. 2016, in *Metal Sustainability: Global Challenges, Consequences, and Prospects*, Izatt, R.M. (Ed.), Wiley, Oxford, U.K., pp. 317-332.

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Economic Comparison of SuperLig®-MRT and Traditional Separation Technologies (Continued)

- **Negative externality costs large with Traditional Separation Technologies, small with SuperLig® - MRT**

- **Minimal environmental costs are involved with SuperLig® - MRT systems compared to large costs to counter negative externality effects for Traditional Separation Technologies**

- **Capex and Opex costs much smaller for SuperLig® - MRT systems because processes are simpler requiring less space, less hardware, fewer chemicals, less labor, less capital investment, fewer separation stages, less energy input, and much lower (minimal) waste generation**

Izatt, S.R., et al. 2016, in *Metal Sustainability: Global Challenges, Consequences, and Prospects*, Izatt, R.M. (Ed.), Wiley, Oxford, U.K., pp. 317-332.

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Summary

- **Several important bottlenecks to sustainability in PGM processing have been identified**
- **SuperLig® - MRT systems have been shown to be capable of overcoming significant bottlenecks in these processes**
- **SuperLig® - MRT processes have significant economic and environmental benefits compared to traditional PGM separation and recovery processes due to their high metal selectivity and simplified flow sheets**