



## A Cyanide-Free Green Process to Recover Gold

Gold is in high demand for products ranging from jewelry to electronics and medical devices. To extract gold from ore, mining companies typically use the sodium cyanide process, in which the gold is converted into a water-soluble coordination complex and activated carbon is used to leach the gold from the slurry. A significant issue associated with this extraction process is that it produces a highly toxic, cyanide-laden waste stream that must undergo extensive, and expensive, treatment. The waste created during extraction has become such a significant issue that environmental impacts are now a deciding factor when considering new gold-mining projects and, because of improper treatment of the waste stream, the sodium cyanide process has been banned in some parts of the world.

Enter Cycladex, a startup company cofounded by Nobel Laureate Sir Fraser Stoddart from Northwestern Univ. Cycladex has developed an environmentally benign method for extracting gold that is also less expensive than the cyanide-based process. In 2013, Stoddart made an accidental discovery when mixing aqueous solutions of  $\alpha$ -cyclodextrin and potassium gold bromide. The  $\alpha$ -cyclodextrin forms a 2:1 complex with potassium gold bromide in what is referred to

as a lock-and-key structure. The two  $\alpha$ -cyclodextrin compounds form the structure of the so-called lock and the potassium gold bromide acts as the key. The key forms the template of the 2:1 complex and the lock forms around the key. The self-assembly of this structure is specific to gold and also to the potassium salt of gold bromide. With support from the National Science Foundation, Cycladex now aims to capitalize on this discovery by using it to extract gold from ores without the use of cyanide-containing chemicals.

Under an exclusive license from Northwestern Univ., the company has designed a new process that integrates the isolation of gold using  $\alpha$ -cyclodextrin with conventional hydrometallurgy for the selective extraction of gold from gold-bearing materials. In this process, gold is leached from the ore using a bromide-based solubilizing agent (lixiviant) that forms a tetrabromoaurate complex with gold. A solution of cornstarch-derived  $\alpha$ -cyclodextrin is added to the leachate; upon addition of the  $\alpha$ -cyclodextrin, the lock-and-key crystal structure forms spontaneously and precipitates. The gold is released from the crystalline precipitate at high temperature to yield solid gold metal.

The Cycladex process can be run on equipment similar to that used for the cyanide process — making it possible to retrofit the new process into existing production facilities. It can also be used to isolate platinum and palladium at

the same time as gold and silver.

Cycladex has compared the new method with the conventional sodium cyanide process by using both to extract gold from an ore from Kyrgyzstan. The Cycladex process had an average yield 5% higher than that of the cyanide-based process. The new process also required less time to extract the gold, which should increase throughput at a manufacturing facility and thus reduce associated operating costs.

According to Roger Pettman, CEO and cofounder of Cycladex, “This new, environmentally friendly gold-recovery process offers a potential 50% reduction in raw material costs and a 35% reduction in capital costs compared to the cyanide process.”

The company is now optimizing the technology to maximize extraction yields. It has determined that the oxidation-reduction potential and the pH of both the initial lixiviant and the in-process ore/leachate system are the most critical parameters for monitoring and controlling the leaching reactions.

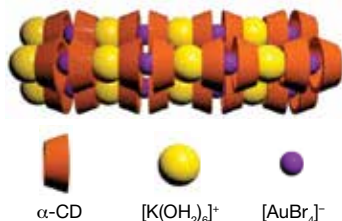
Cycladex is scaling up the method at the Comstock mine in Nevada. Its goal is to move from the current metric-ton scale to commercial scale by mid-2018, which will involve isolating gold from more than 100,000 m.t. of ore.

“Comstock Mining is an emerging leader in sustainable, responsible mining, having been nominated for multiple environmental and cultural awards, and winning first place in Nevada for excellence in reclamation,” says Corrado De Gasperis, executive chairman and CEO of Comstock Mining, Inc. “We remain focused on commercializing this innovative, economic, and environmentally friendly technology with Cycladex.”

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$\alpha$ -Cyclodextrin/H<sub>2</sub>O  
+  
KAuBr<sub>4</sub>/H<sub>2</sub>O



▲ A new process for extracting gold from ore is based on the fact that  $\alpha$ -cyclodextrin ( $\alpha$ -CD) and potassium tetrabromoaurate (KAuBr<sub>4</sub>) spontaneously self-assemble into a crystal structure.

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