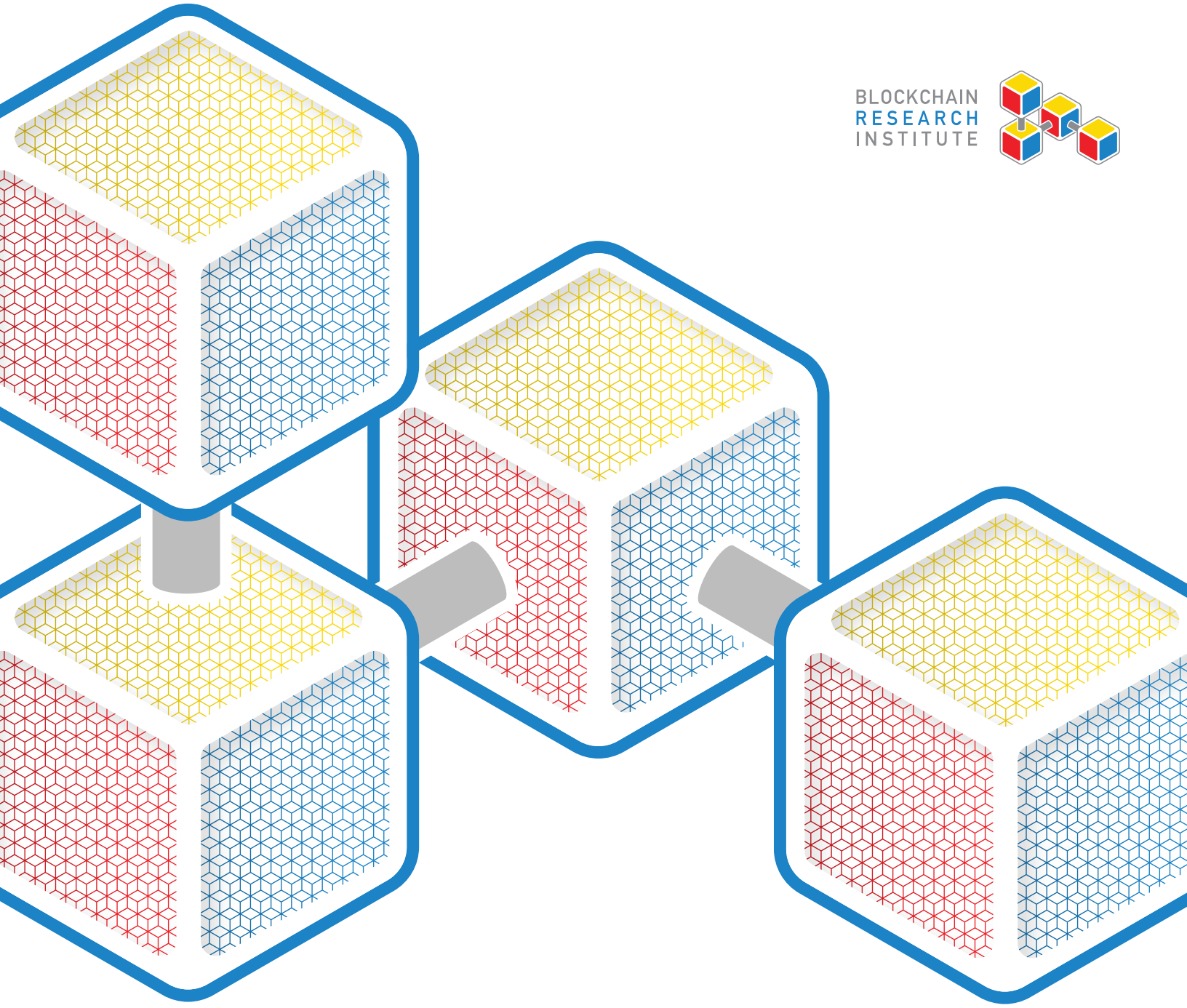
BLOCKCHAIN RESEARCH INSTITUTE



BLOCKCHAIN AND THE FUTURE OF BATTERY SUPPLY CHAINS

How Circulor Enables Ethically Sourced Cobalt

Anthony D. Williams
DEEP Centre

December 2019

A BLOCKCHAIN RESEARCH INSTITUTE LIGHTHOUSE CASE STUDY

Realizing the new promise of the digital economy

In 1994, Don Tapscott coined the phrase, "the digital economy," with his book of that title. It discussed how the Web and the Internet of information would bring important changes in business and society. Today the Internet of value creates profound new possibilities.

In 2017, Don and Alex Tapscott launched the Blockchain Research Institute to help realize the new promise of the digital economy. We research the strategic implications of blockchain technology and produce practical insights to contribute global blockchain knowledge and help our members navigate this revolution.

Our findings, conclusions, and recommendations are initially proprietary to our members and ultimately released to the public in support of our mission. To find out more, please visit www.blockchainresearchinstitute.org.

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Foreword

At the Blockchain Research Institute, we believe that some of the most important blockchain applications will be those that solve society's biggest problems. Human civilization stands at an environmental crisis point, and recycling waste is vitally important. Makers of batteries for such consumables as smartphones and electric vehicles require more and more cobalt, but the mineral is currently being mined in an unsafe manner, often by children. These problems seem destined to get worse as we search for the harder-to-reach caches of cobalt. We think that blockchain technology can effectively address these problems.

This project deftly describes the challenges that face the cobalt industry—challenges that will grow as the demand for the ferromagnetic metal skyrockets. It explains how blockchain technology has the potential to improve the situation by monitoring a clean chain of custody, stewarding an ethical supply chain, and improving governance of all market participants including bad actors. This will not be an easy problem to solve. The project leader Anthony D. Williams soberly outlines the implementation challenges and describes how innovators can overcome them. He distills key lessons for applying blockchain to other resource dilemmas.

This project deftly describes the challenges that face the cobalt industryand explains how blockchain technology has the potential to improve the situation.

This is Williams' fifth project with the BRI. It follows his case studies on Everledger's ethical diamond supply chain and Blockscale Solutions' Ethereum-based land registry in the Indian state of Haryana. Williams is also the co-author of *Wikinomics: How Mass Collaboration Changes Everything*, and its sequel, *Macrowikinomics: New Solutions for a Connected Planet* and is the co-founder and president of the DEEP Centre. He cares deeply about human rights as well as environmental sustainability, and this is the kind of research that makes a difference.

ALEX TAPSCOTT
Co-Founder
Blockchain Research Institute

Case in brief

» As the demand for electric vehicles (and their batteries) is set to soar, the demand for battery raw materials like cobalt will skyrocket. These materials are mined as rock in places like the Democratic Republic of the Congo known for human rights violations. Then they undergo a complex metamorphosis through multiple processing steps in different countries, before finally being installed as batteries inside cars, mobile phones, and other electronics.

- This is a complex traceability problem that encompasses the life cycle of cobalt, from extraction, processing, and manufacturing through to battery recycling. With a focus on industry leaders such as Circulor, this research documents industry efforts to solve the traceability problem along a multifaceted supply chain, thereby ensuring conflict-free, ethically sourced minerals.
- Implementation challenges include reaching consensus on responsible sourcing standards; the murky traceability of cobalt materials, especially after they have been aggregated; the need to reconcile the imperative for transparency with the desire to protect strategically important data; the lack of digitization among upstream supply-chain participants' systems; and the various costs associated with operationalizing a blockchain solution.

This research documents industry efforts to solve the traceability problem along a multifaceted supply chain, thereby ensuring conflict-free, ethically sourced minerals.

Problem to be solved

If challenged to identify the essential technologies that have powered the digital revolution, one would quickly and quite reasonably point to microprocessors, personal computers, cell phones, wireless telephony, and the Internet. One could also add the lithium-ion battery to that list. Indeed, the world today would be a very different place without the ubiquitous connectivity and instant communications enabled by our battery-powered smartphones, tablets, wristwatches, and other wearables. As we move farther into the 21st century, lithium-ion batteries will also provide a vital, resilient, and even peer-to-peer energy source for an entire new generation of world-changing technologies, from the industrial Internet and advanced robotics to smart homes, autonomous vehicles, and countless other applications.

In short, the advanced battery and its supply chain is an inexorable component of modern life. Now, with electric vehicles (EVs) set to sweep the global automotive market, demand for lithium-ion batteries is expected to increase dramatically (Figure 1, next page).[1]

Deemed a critical raw material by the European Union, cobalt has unique properties that make it a vital component of high-performance alloys and lithium-ion batteries.

Lithium-ion battery manufacturing, in turn, fundamentally depends on access to the requisite raw materials, especially the essential minerals in the battery cathodes, which include nickel, lithium, copper, and cobalt.

While a number of rare minerals are plagued by ethical sourcing concerns, cobalt arguably presents the biggest concern for EV makers. Deemed a critical raw material by the European Union, cobalt has unique properties that make it a vital component of high-performance alloys and lithium-ion batteries.[2] Cobalt is not only a super-high-density energy material; its properties enhance the longevity and thermal stability of lithium-ion batteries as well.[3] Largely mined as a by-product of nickel and copper, chemically

refined cobalt is sold to battery manufacturers like Samsung and LG Chem, which in turn provide rechargeable lithium-ion batteries to automotive manufacturers such as Tesla, Renault, Nissan, and Mitsubishi. The problem, according to Mark LaPedus of *Semiconductor Engineering*, is that "the rapid growth of electric vehicles is creating an enormous demand for cobalt, causing tight supply, high prices, and ethical supply chain issues for this critical material."[4]

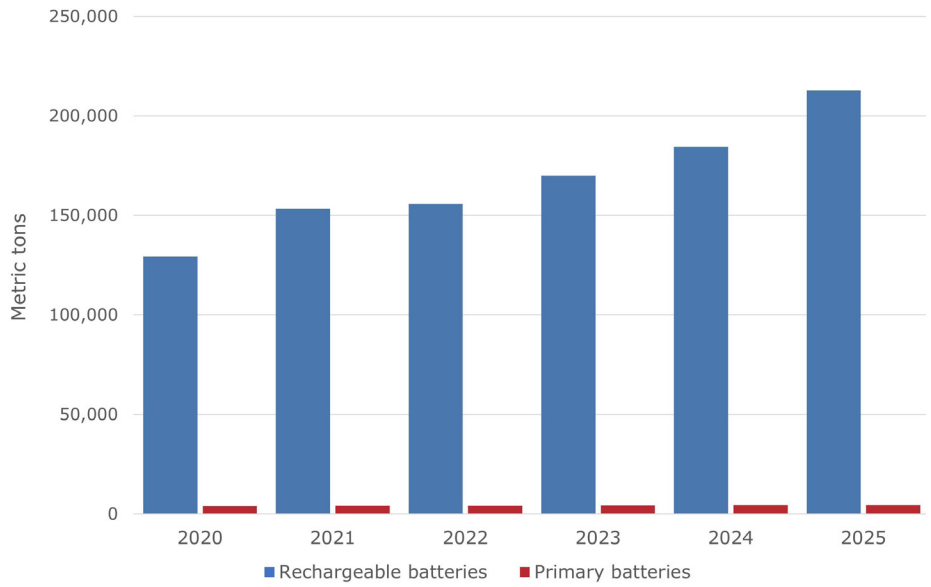
Today, the mining industry produces enough cobalt to meet demand for electric vehicles and other uses, but it might be a different story in the next decade.

Today, the mining industry produces enough cobalt to meet demand for electric vehicles and other uses, but it might be a different story in the next decade. Whereas a smartphone contains five to twenty grams of cobalt, just one electric car battery contains between four and thirty kilograms, depending on the battery's composition and capacity.[5] As demand for EVs ramps up, companies like Tesla and Panasonic have expressed concern about whether there will be a reliable supply of cobalt to meet future production needs.[6]

According to Deloitte, EV sales will grow from "two million units in 2018, to four million in 2020, 12 million in 2025, before rising to 21 in 2030 as policy and regulation converge with consumer demand and advances in battery manufacturing." Specifically, Deloitte forecasts that "the market will reach a tipping point in 2022 when the total cost of ownership for an EV is on par with its internal combustion engine counterparts."[7]

According to Caspar Rawles, a senior analyst with Benchmark Mineral Intelligence, there is general consensus within the industry that mass adoption of EVs in the early 2020s will push the cobalt market into a sustained period of shortages until new deposits or

Figure 1: Estimated demand for lithium batteries



Source of data: "Projection of worldwide lithium demand for batteries from 2017 to 2025, by type," Statista Inc., April 2017.

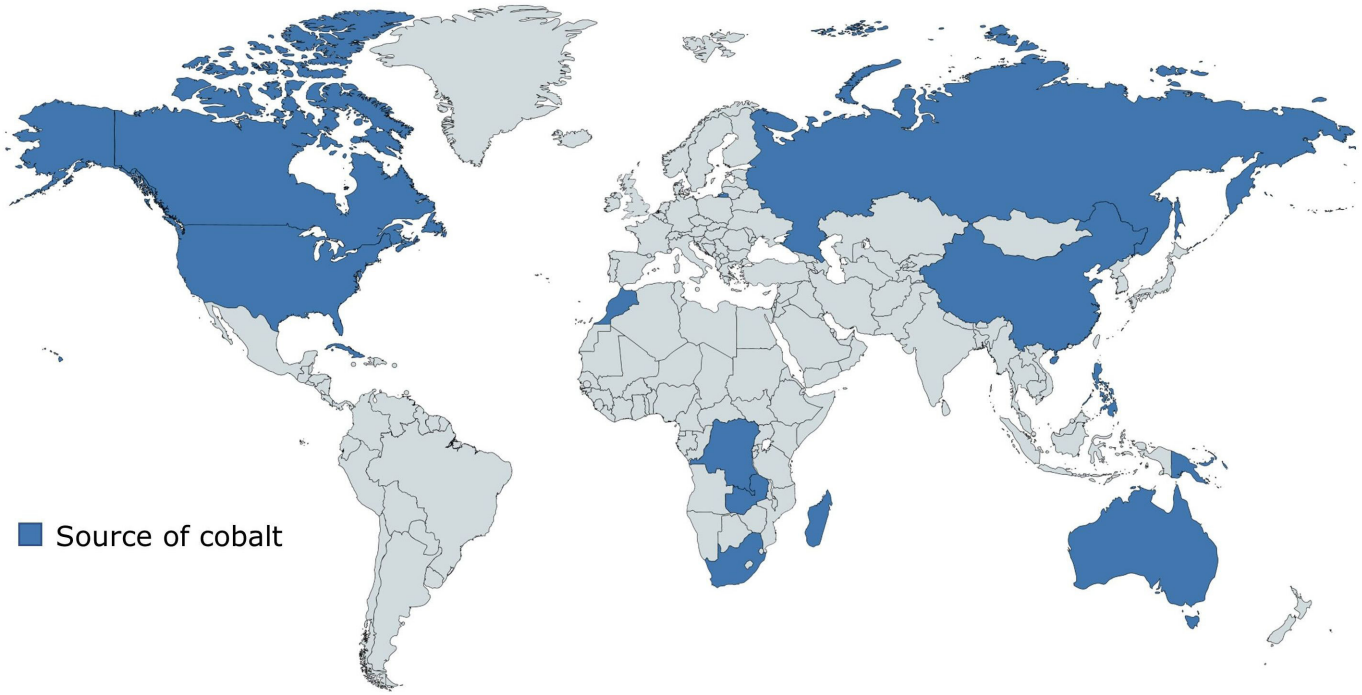
alternative battery chemistries/technologies are developed.[8] Some estimates suggest that cobalt production will need to more than double from 2016 levels by 2025 to keep up with electric car battery manufacturing, creating a potential 20 percent gap between supply and demand.[9]

The mismatch between the supply and demand for cobalt is a serious concern.

To compound matters, electrification (and hence the demand for lithium-ion batteries and their component minerals) is reaching into a wide range of other transportation and machinery domains that could further amplify demand. In his testimony to the US Senate Committee on Energy and Natural Resources in May 2019, Dr. John Warner, chairman of the National Alliance for Advanced Technology Batteries, warned that these sources of increased demand include the "marine and maritime segments; construction, mining, forestry, and agricultural vehicles; industrial vehicles; aerospace, drones and satellites; robotics; and even the medium and heavy truck segments."[10]

The mismatch between the supply and demand for cobalt is a serious concern—one that could foreseeably constrain EV adoption if more production capacity cannot be brought online quickly, or if the industry is unable to engineer a radical shift toward less cobalt-intensive batteries.[11] However, there is also a darker side to cobalt: a long history of human rights violations, including child labor, associated with production in the Democratic Republic of the Congo (DRC).

Figure 2: Top sources of cobalt in the world



Sources of data: US Geological Survey, "Mineral Commodity Summaries," Feb. 2019. Ryota Kikkawa, "World Focuses on the EV Battery Material Cobalt," Marubeni Research Institute, 29 March 2019.

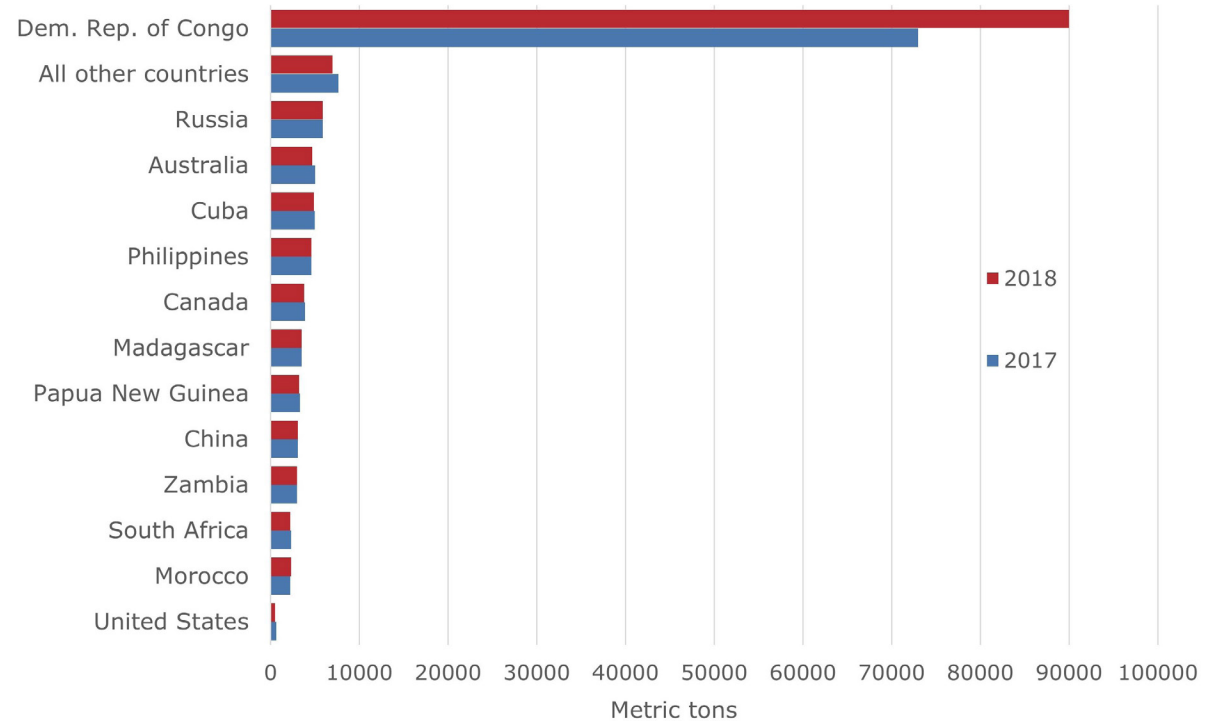
Batteries are costly and extremely difficult to recycle, often resulting in the disposal of spent but still toxic batteries in local landfills.

While EVs are often positioned as an environmentally responsible transportation option, there are also serious environmental costs associated with the production and disposal of EV batteries. The mineral extraction process is energy- and water-intensive and produces toxic by-products that can contaminate groundwater and local waterways.[12] Batteries are also costly and extremely difficult to recycle, often resulting in the disposal of spent but still toxic batteries in local landfills.[13] The estimated rate of battery recycling is five percent in Europe and North America, and less in other jurisdictions. Industry analysts predict that the volume of spent lithium-ion batteries will hit two million metric tons per year by 2030.[14]

The human cost of cobalt mining

Most of the world's known reserves of cobalt are contained in the copper belt in DRC and Zambia.[15] The DRC alone accounted for over 64 percent of global production in 2018, which makes the cobalt supply chain especially precarious (Figure 3). The DRC is among the poorest, most corrupt, and most coercive countries on Earth. In 2018, it was ranked 151 out of 162 countries in the Cato Institute's Human Freedom Index, 161 out of 180 countries in the Transparency International's Corruption Perceptions Index, and 176 out of 188 countries on the United Nations' 2018 Human Development Index with a gross domestic product of $796 per capita.[16]

Figure 3: Global production of cobalt



Sources of data: US Geological Survey, "Mineral Commodity Summaries," Feb. 2019. Ryota Kikkawa, "World Focuses on the EV Battery Material Cobalt," Marubeni Research Institute, 29 March 2019.

According to the DRC's own estimates, 20 percent of the cobalt production comes from artisanal miners—independent workers who work alongside larger industrial mining operations but dig holes and extract ore with picks and shovels. Traditionally, artisanal miners have sold their ore to local cooperatives, which then sell it to local merchants and traders. They, in turn, sell to international traders or operating mines with established transport links and the artisanal mined cobalt ends up being exported to China as concentrate.

Children involved in the cobalt trade work up to 12 hours a day, can be as young as seven years old, and receive as little as two dollars a day for their efforts.

Amnesty International estimates that there are approximately 110,000 to 150,000 artisanal miners in the DRC, and UNICEF alleges that up to 40,000 of those are children.[17] Children involved in the cobalt trade work up to 12 hours a day, can be as young as seven years old, and receive as little as two dollars a day for their efforts.[18] However, the region's intense poverty and the mineral's soaring price continues to attract thousands of impoverished Congolese to the cobalt-rich areas to secure an income.

Every year, dozens of unregulated, artisanal miners lose their lives to mining disasters across the Congo. On 27 June 2019, 36 artisanal miners were killed in a Glencore mine collapse. As the day went on, the reported death toll rose to 43.[19] Glencore, one of the world's largest mining companies, has reported a growing number of illegal miners on their sites in the DRC, calling them "daily intrusions." They estimate upward of 2,000 artisanal miners trespass on their properties every day.[20] As perilous as illegal cobalt mining can be to the lives of the miners, exposure to toxic levels of metals is also having widespread health implications for the miners and their families.

The areas surrounding mining locations in Kolwezi are proving to be some of the most polluted in the world, with high levels of metals found in the region's fish and soil samples. For residents who live near the mines, a study found that urinary concentrations of cobalt were 43 times higher than the average, with lead being five times higher, and cadmium and uranium four times higher.[21]

Lack of protective clothing and breathing apparatuses increases miners' exposure to harmful dust and minerals that can have far-reaching health implications.

Additionally, lack of protective clothing and breathing apparatuses increases miners' exposure to harmful dust and minerals that can have far-reaching health implications. The long-term effects can include thyroid conditions, heart damage, and breathing problems.[22] Even more disturbing are the increasing number of severe and rare birth defects. University researchers and epidemiologists have documented extremely rare birth defects such as holoprosencephaly, a rare brain defect that causes skull and facial malformations in heavy mining regions like Lubumbashi.[23]

Alternatives to cobalt?

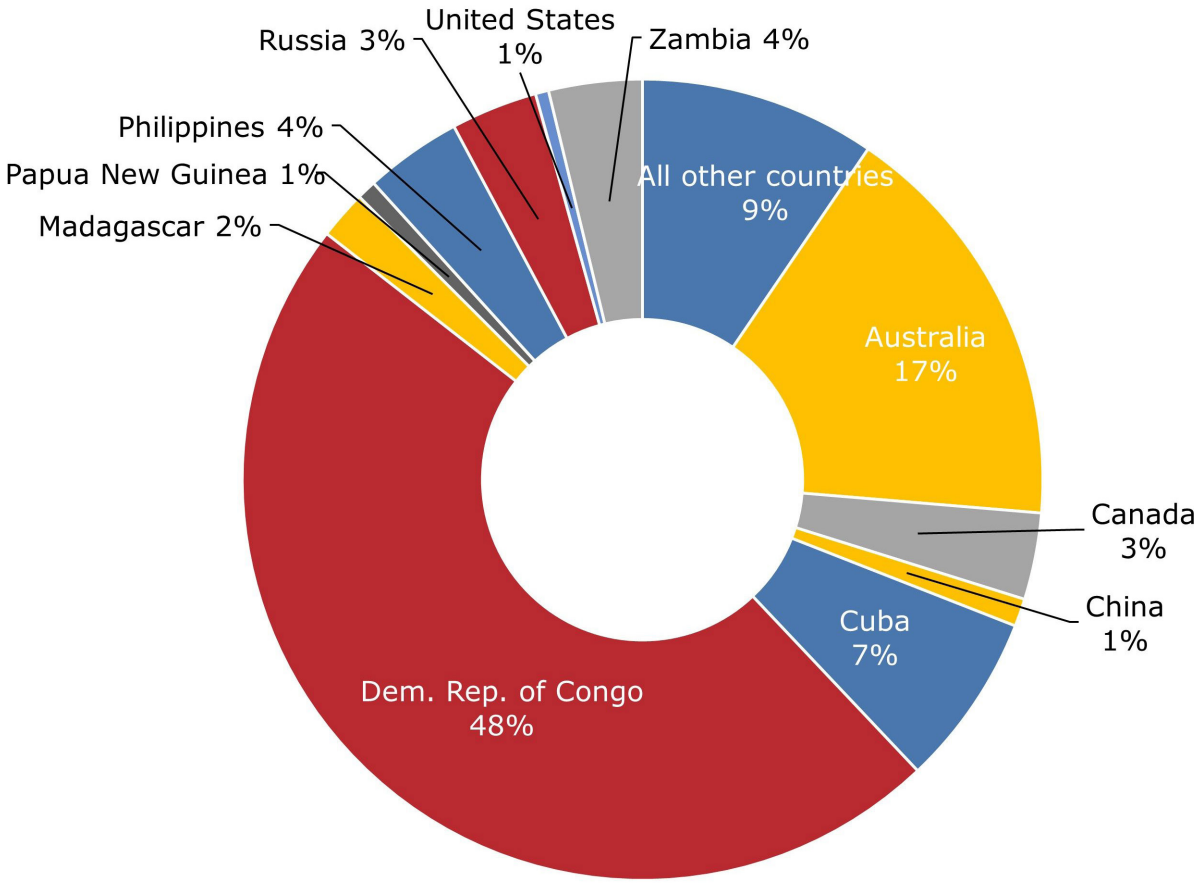
While the industry is exploring other sources of cobalt supply in British Columbia, Idaho, the Northwest Territories, and Ontario, the DRC is likely to be the principal source of supply for the next decade. Russia, Australia, Canada, and Cuba—the next largest suppliers—account for only 13 percent of global production capacity collectively,

and currently all mine capacity expansion projects outside of Africa are in early stages of development.[24] As Rawles of Benchmark Mineral Intelligence put it, "Without the DRC, this ramp-up in EVs won't happen."[25]

Many industry heavyweights, including Panasonic, Tesla, BMW, and Honda, are working on new batteries that will alter the cathode chemistry to lessen the reliance on cobalt.

Many industry heavyweights, including Panasonic, Tesla, BMW, and Honda, are working on new batteries that will alter the cathode chemistry to lessen the reliance on cobalt. In 2018, Elon Musk declared that batteries for the Tesla Model 3 will use less than three percent cobalt, and the next generation battery "will use none" of the material. However, there is no clear timeline for delivering next-generation batteries, and most observers are skeptical that cobalt can be eliminated completely without causing performance issues, including greater volatility and an increased risk of a flammable event.[26] "You cannot eliminate cobalt below five percent, or the structure of the lithium-ion battery breaks down," said Robin Goad, president and chief executive officer of Canada's Fortune Minerals. "All of the major battery manufacturers will tell you that cobalt is going to be part of the chemistry for batteries at least for the next decade, if not two decades."[27]

Figure 4: Global cobalt reserves



Sources of data: US Geological Survey, "Mineral Commodity Summaries," Feb. 2019. Ryota Kikkawa, "World Focuses on the EV Battery Material Cobalt," Marubeni Research Institute, 29 March 2019.

A new way forward: An ethical cobalt supply chain

Major electronics and car manufacturers have vowed not to tolerate child labor in their supply chains. Apple, Samsung, Sony, and others have joined the Responsible Cobalt Initiative.

Neither cobalt-free batteries, nor alternative sources of cobalt supply outside of the DRC, will provide a realistic short-term solution to the industry's woes. Major electronics and car manufacturers have vowed, in the meantime, not to tolerate child labor and other abuses in their supply chains. Apple, Samsung, Sony, and several brand-name companies have joined the Responsible Cobalt Initiative, which was established in 2016 under the China Chamber of Commerce of Metals, Minerals, and Chemicals Importers and Exporters to establish a code of conduct for an ethical cobalt supply chain.[28] The framework, which was modeled on the Organisation for Economic Co-operation and Development's "Due Diligence Guidance on Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas," calls on companies to trace how their cobalt is extracted, transported, manufactured, and sold.[29]

Greater transparency and traceability in the cobalt supply chain will ultimately be good for industry and could provide a catalyst for addressing some of the DRC's human rights challenges. The need to operationalize these commitments quickly in order to source cobalt ethically, however, has presented major *original equipment manufacturers* (OEMs) in the electronics and EV market with a daunting challenge. The cobalt supply chain is complex, with many stakeholders and production stages involved in transforming raw ore into end products. While extracted in places like the DRC, cobalt undergoes a complex metamorphosis through multiple processing steps in different countries before it is installed as batteries inside cars, mobile phones, and other electronics. Corruption, opacity, and poor regulation in the DRC have made it difficult for mining companies, processors, and manufacturers to verify reliably that the minerals have not been tainted by child labor and other problems.

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The industry also lacks data standards and a viable infrastructure to trace the flow of cobalt through the various stages of the supply chain. However, as explored further below, a number of leading companies are leveraging a combination of new technologies, including blockchain, to resolve these complex traceability challenges.

Blockchain solutions for tracking and traceability in the cobalt supply chain

The supply-chain transparency and tracking challenges facing OEMs in the electronics and EV market are not unique to cobalt. Provenance and traceability are vexing challenges for a wide range of companies and their supply chains. Whether eliminating conflict stones from the global trade in rough diamonds or tracking the offshore manufacturing processes used to assemble iPhones and luxury apparel items, brand-conscious companies increasingly need

complete visibility into the business practices of even the most distant suppliers.

Along with complementary Internet of Things technologies like sensors and radio-frequency identification, blockchain is helping answer these concerns by providing new tools for tracking goods across extended supply chains, ensuring that what occurs at each point in the chain can be chronologically recorded on a distributed ledger. Companies can use the immutable record encoded on a blockchain, in turn, to reassure consumers, regulators, and other stakeholders that their end products have been ethically sourced.

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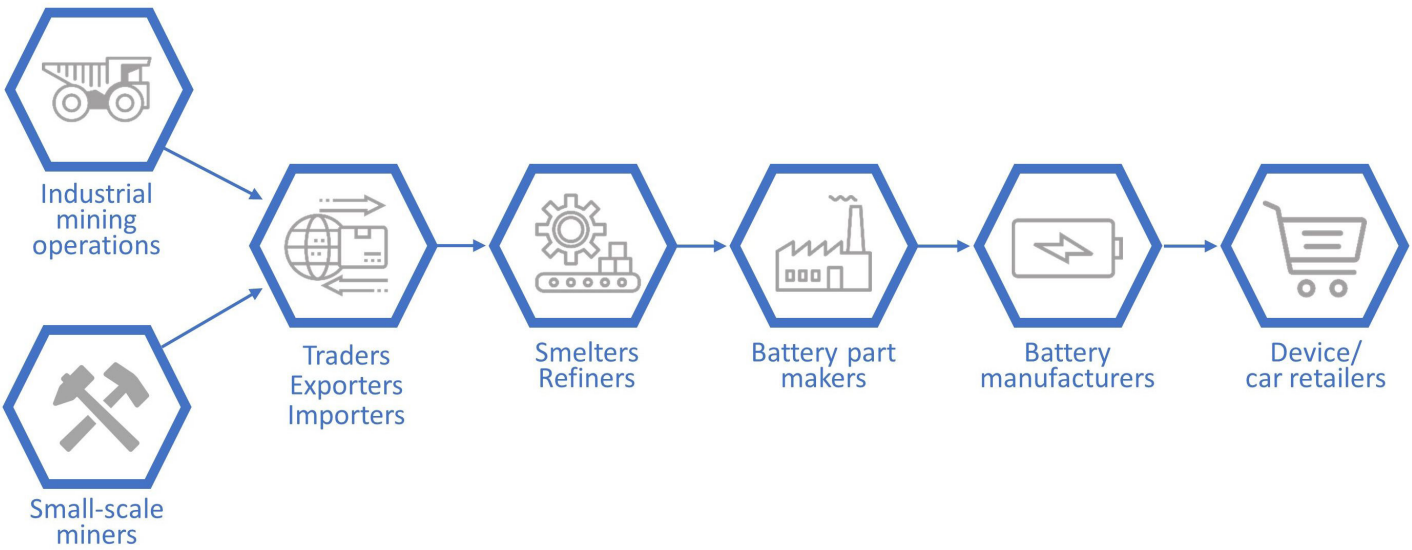
Creating a clear chain of custody

The foundation of any provenance and traceability protocol for minerals such as cobalt should include what ethical sourcing experts call a robust chain of custody (CoC).[30] According to RCS Global, a leader in data-driven responsible sourcing of natural resources, a chain of custody is defined as "all steps in a supply chain that takes possession of the product, including manufacturers, exporters, traders, and importers" (Figure 5).[31] The research group asserts that the stakeholders concerns about provenance and methods of production along the supply chain can be addressed through the greater traceability enabled by a robust CoC system.

In the case of cobalt, a clear CoC identifies minerals from source to delivery, recording each transaction to ensure the materials passed from miners to refiners and processes and eventually to manufacturers have an ethical origin. In practice, OEMs in electronics and automotive sectors have found that determining a clear CoC for

Figure 5: Cobalt supply chain



Source of data: "'This Is What We Die For': Human Rights Abuses in the Democratic Republic of the Congo Power The Global Trade In Cobalt," Amnesty International (AFR 62/3183/2016), 15 Jan. 2016.

cobalt comes with a number of challenges. For example, minerals from both artisanal and industrial mines frequently arrive at the same aggregation points in the DRC before being exported for refining and smelting, making it difficult to identify the source of the combined minerals. Prior to arriving at the refinery/smelter, the materials will likely also encounter multiple points of transformation, such as crushing, washing, grinding, and separation; these can further blur the origin of the minerals. Additionally, there may be a lack of technical capacity, such as language, personnel, and record keeping, especially for less sophisticated supply-chain operations.

We focus our attention on the work Circulor is doing with automotive companies to track the supply of ethically sourced cobalt.

RCS Global and platform providers like Circulor have focused their efforts on using blockchain solutions to improve and increase the resiliency of CoC systems. They propose that a well-developed CoC system enabled by blockchain can facilitate two outcomes: "material stewardship," or the ability to track ownership of materials at various points in the supply chain; and "responsible production," or materials produced to a particular standard.[32] While several organizations are undertaking blockchain pilot projects, we focus our attention on the work Circulor is doing with automotive companies to track the supply of ethically sourced cobalt.

Circulor enables supply-chain traceability for minerals and natural resources

UK-based company Circulor has developed a suite of blockchain-enabled tools to enable supply participants to document the provenance of the mineral and natural resources that end up in their products. The Circulor System enables suppliers and buyers to follow raw materials through the production process, creating an immutable audit trail that provides all parties with a near real-time view of the supply chain. While the challenges surrounding cobalt production was the catalyst for the company forming, parties can use the platform to track the provenance of any material, from palm oil to beef, and demonstrate sustainable sourcing practices. In fact, Circulor's first public project focused on the mining of tantalum, one of the four conflict minerals identified by the Organisation for Economic Co-operation and Development (OECD). The others are tin, tungsten, and gold.[33]

Companies such as Apple and Samsung are keen to prove that, like cobalt, the tantalum used in their devices are conflict-free.

Used in the capacitors found in a wide range of consumer electronics, Tantalum is subject to many of the same problems as other conflict materials. Unearthed in central Africa, it is shipped to refineries and component manufacturers in Asia, and then winds up in smartphones, laptops, game consoles, and other devices sold to consumers around the world. Companies such as Apple and Samsung are keen to prove that, like cobalt, the tantalum used in their devices are conflict-free.

Circulor signed an agreement in 2018 with the Rwandan government and mining association to use its blockchain system to track raw materials extracted in Rwanda all the way through the supply chain, from mine to shelf. While the small mining companies get to use the

blockchain system for free, companies further up the supply chain are charged a fee. The economics of Circulor's traceability solution made it much easier to get both the Rwandan government and the country's tantalum producers onboard. As Circulor founder Doug Johnson-Poensgen explained:

> *Existing bag and tag schemes are expensive for upstream participants. Solutions like ours allow downstream to pay for traceability making our solution effectively free for small and medium upstream participants. The Rwandan government saw this as an opportunity to give its producers a competitive edge with electronic manufacturers by proving that Rwanda is a conflict-free source of tantalum and other minerals.*[34]

In Circulor's cobalt-related efforts, the company is working with automakers such as BMW and Volvo to demonstrate responsible cobalt sourcing practices.

Circulor's first client in Rwanda is Power Resources Group, a tier-two supplier of Apple, which provides refined material to a tier-one Apple supplier, a manufacturer of capacitors.

In Circulor's cobalt-related efforts, the company is working with automakers such as BMW and Volvo to demonstrate responsible cobalt sourcing practices. In the case of BMW, Circulor is helping the company trace already known clean sources of cobalt coming from Australia, Canada, the United States, and certain well-regulated operations within the DRC.[35] Companies and operations mining and producing cobalt will not be added to Circulor's ledger until they can demonstrate that they are sourcing the mineral responsibly. In order to do so, Johnson-Poensgen is testing the system with known sources of clean cobalt. "It makes economic sense to start with sources that aren't a problem," said Johnson-Poensgen. "Once the system is proven and operating at scale, one can tackle the harder use cases like artisanal miners."[36]

Volvo, on the other hand, has been using recycled cobalt in its electric car batteries as a means to avoid the problems associated with sourcing raw cobalt from the DRC. The blockchain project with Circulor tracked cobalt produced at a Chinese recycling plant to Volvo's manufacturing plant in Zhejiang, China, over a two-month period in 2019.[37]

Circulor combines rigorous processes with smart technology

Circulor's approach to supply-chain traceability combines technology with rigorous protocols, third-party audits, and on-the-ground due diligence.

Tracking a raw material through a supply chain boils down to solving two core problems: (1) reliably digitizing the commodity at the source, and (2) connecting the input materials to the output product at any step in the supply chain. While blockchain technology is part of the solution, blockchain alone is not enough. As Johnson-Poensgen explained, "A blockchain will record an immutable record of custody of a material, the locations it's traveled through, its composition over time, and all that, but if you're trying to make sure the wrong material never enters the system in the first place, you need processes to make this work." Accordingly, Circulor's approach to supply-chain traceability combines technology with rigorous protocols, third-party audits, and on-the-ground due diligence.

The technology component of Circulor's solution is built on the distributed, permissioned ledger written on Hyperledger Fabric and hosted on the Oracle Blockchain Platform. According to Johnson-Poensgen, Circulor chose Fabric for several practical reasons:

> *Hyperledger Fabric is as close to an enterprise standard as exists in blockchain, was designed for confidential transactions and didn't need crypto to function. Corda was developed for use in financial services and is still not as cross-industry capable as Fabric. Although our first prototypes were built on Ethereum, we felt that a ledger requiring crypto to pay for the consensus mechanism, privacy concerns, network delays for committing transactions, and a proof of work consensus mechanism that was energy hungry made Ethereum inappropriate for commercial use at scale.*[38]

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The Circulor platform provides the infrastructure for scanning and tracking the EV battery components at each location and stage of the process, from the mines and aggregation sites through to the cobalt refineries and cathode manufacturing plants. While blockchain technology serves as the secure ledger for recording data, Circulor uses other technologies to flesh out the solution. For example, the start-up developed mobile scanning applications to enable midstream refiners, recyclers, and cathode manufacturers to track the flow of materials through their operations. "Many of the midstream supply chain participants in China don't have scan-in scan-out technologies or sophisticated quality management systems," said Johnson-Poensgen. "Almost everything still gets done on paper."

The processes that complement this technology platform are vital to ensuring that Circulor is tracking only cobalt from legitimate and well-managed mining concessions through its platform. To begin with, Circulor allows only accredited mining sites to access the platform. To be accredited, these sites must have perimeter fencing, security details, and measures that prevent pregnant women and children from working in their mines. Most also have safety protocols in place that limit the depth of the pits that miners can work in, with working conditions that more closely resemble EU standards. To vet the mining sites, Circulor partnered with Kumi Consulting, a specialist in responsible sourcing and the sole auditor for EU conflict-minerals regulations. In other words, Kumi performs the litmus test on whether a mining location is operating responsibly and whether the cobalt from these sites has been extracted ethically.

Vetting participants is step one in establishing an ethical cobalt supply chain. Step two is digitizing the cobalt at source, which effectively initiates the chain of custody in Circulor's system.

Vetting participants is step one in establishing an ethical cobalt supply chain. Step two is digitizing the cobalt at source, which effectively initiates the chain of custody in Circulor's system. The digitization process starts at the aggregation sites where cobalt from vetted industrial mines is placed in secure bags, tagged with a QR code, and recorded on Circulor's blockchain. Extra precautions, including use of a facial recognition app to tighten security, are taken to ensure that the onsite person inputting data into the system is a trusted source.

"We focus on reliably capturing four things: who's bringing the material; who's recording the data to our system for the first time; where are they; and, finally, we assign an identity to a bagged quantity of raw cobalt in order to track it through the supply chain," explained Johnson-Poensgen. The identity tags issued by Circulor's system include attributes about how, where, when, and by whom the materials are going to be used at various stages of the production process. "What that means is that there's no black market for these materials, because 'used anywhere else by anyone else' immediately flags the material as an anomaly."[39]

The third and arguably trickiest step is tracking the chain of custody through the subsequent refining and production stages in the supply chain. To do that, Circulor developed a protocol called Dynamic Identity, which uses a number of smart contracts to enforce agreed tests on the data about a production or manufacturing process, to judge whether the materials in the end product of that process can be reliably connected to the original input materials. One of the basic tests used in the Dynamic Identity process is called "mass balance," which is an application of the conservation of mass principle that accounts for materials leaving and entering a process. Another test is a "proof of elapsed time." If a manufacturing process takes 15 days, for example, then it is clear that materials that arrived on Monday can't be the same vetted materials in the output product the following day.[40] The tests are effectively coded as rules; if the tests are passed, it allows manufacturers to claim that their input materials have been ethically sourced.

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DOUG JOHNSON-POENSGEN
Founder
Circulor

Data governance—that is, who gets access to Circulor's traceability solution, including who can add and view data on the ledger—is critical to maintaining the integrity of the results. Like many enterprise blockchain applications, Circulor uses a private permissioned system. Johnson-Poensgen explained, "Users are only able to see the data they are permissioned to see, which generally includes their own data and the subset of data generated by their suppliers that comes to them."[41] Any changes to the ledger are done by users subject to data integrity checks and data validation checks, for which Circulor uses artificial intelligence/machine learning as well as the validation rules described above.

In these early days of establishing an ethical cobalt supply chain, on-the-ground due diligence is also important at all stages of the process. Johnson-Poensgen explained:

> *At each of these facilities there is some element of due diligence on the ground to make sure that materials are processed in batches and that the batches are segregated. This means that known provenance materials are not mixed with unknown provenance materials. The combination of physical audit, plus the integrity of process is what gives us that reliable chain of custody.*[42]

Johnson-Poensgen points to Volvo, noting that the company wants to be 100 percent certain that it knows where all the cobalt in its

batteries has come from. "That's done essentially by requiring a segregated process all the way through the supply chain, which is enforced by our blockchain solution," he said.[43]

While Circulor is working with BMW, Volvo, and others in the EV market today, Johnson-Poensgen hopes the group will expand to include companies from the aerospace, consumer electronics, and other mining sectors in the near future. After all, the provenance of the cobalt in EV batteries is just one in a wide range of things that go into manufacturing cars and electronics that could have ethical sourcing implications. In fact, the European Commission recently published a report identifying 18 materials around which they would like to see industry implement responsible sourcing practices.[44] Beyond cobalt and the EV market, there are sustainability concerns surrounding most natural resources. "Deforestation, industrial farming, flooding, chemical contamination, and dislocation of communities are just some of the issues that both manufacturers and consumers need to be aware of," said Johnson-Poensgen.[45]

While Circulor is working with BMW, Volvo, and others in the EV market today, Johnson-Poensgen hopes the group will expand to include companies from the aerospace, consumer electronics, and other mining sectors in the near future.

Implementation challenges

In designing a traceability solution for the cobalt supply chain, Circulor and its partners have encountered several implementation challenges.

Achieving consensus on responsible sourcing standards

Responsible sourcing is by no means a new idea, and several industries have well-established standards and norms of behavior. While multilateral organizations such as OECD have issued guidelines on responsible sourcing for the mining sector, there is still a lack of consensus across the industry about how best to implement these guidelines in the cobalt supply chain. Among the contentious issues is how to handle the role of artisanal miners going forward. While OEMs are keen to avoid the risk of inadvertently using raw materials sourced from child labor, cutting artisanal miners out of the supply chain completely could deprive the local population of a vital source of income. As George Heppel of the CRU Group explained, "When done correctly, artisanal mining can be an ethical source of low-cost, high-grade cobalt which also puts income directly into the hands of locals with very few alternative options available to them."[46]

While multilateral organizations such as OECD have issued guidelines on responsible sourcing for the mining sector, there is still a lack of consensus across the industry about how best to implement these guidelines in the cobalt supply chain.

Demystifying the murky traceability of cobalt

The prevalence of artisanal and small-scale mining operations is challenging the ability of the major players in the cobalt supply chain to perform adequate due diligence on the conditions under which the raw materials are mined. The fact that cobalt is often mined and produced as a by-product of other minerals like iron

and nickel also makes it hard to track. IBM, which is also running a cobalt traceability pilot, claims to be exploring the use of chemical analysis to pinpoint the origin of cobalt and ensure so-called clean cobalt was not smelted with minerals sourced less responsibly. Circulor is addressing the challenge by carefully vetting participants, implementing tight security over who can access the system, deploying its dynamic identity protocols, and performing due diligence on the ground. As Johnson-Poensgen put it, "The real challenges are mapping supply chain, making sure that the data is reliable, and enforcing some discipline on who's allowed to do it and whether you can trust it."[47]

"The real challenges are mapping supply chain, making sure that the data is reliable, and enforcing some discipline on who's allowed to do it and whether you can trust it."

DOUG JOHNSON-POENSGEN
Founder
Circulor

Scaling a cost-effective traceability solution across industries

Thousands of companies around the world rely on cobalt as an integral part of their products, making the task of scaling an ethical sourcing solution across several different industries particularly challenging. EV makers are in the spotlight today because of the large quantities of cobalt required to manufacture their batteries. However, the lustrous, silver-gray metal is also a vital component of high-performance alloys used in gas turbines, jet engines, orthopedic implants, and more. In other words, the headway made with leading EV makers and electronics firms is still just one slice of the business world that will need to be engaged in finding solutions to cobalt supply-chain challenges.

That said, Circulor argues that effective traceability can be achieved by engaging critical nodes at each tier of the supply chain. "Participants at every supplier tier from source to OEM need to participate to enable end-to-end traceability, but that doesn't mean you need large numbers at every tier to gain benefit," said Johnson-Poensgen:

> *Currently we start at the OEM and map back to the upstream source. Then you track material flow through to the downstream participants. It could be as few as 4 participants [e.g., OEM, component manufacturer, refiner, mine]. Obviously, few supply chains are that linear or short, and most supply chains are networks. However, if you can map a path, you can provide traceability if the participants at each tier join in.*[48]

Effectively demonstrating a chain of custody is a time-consuming process that takes a large amount of effort and commitment from participating actors.

Finding the resources required to implement ethical sourcing solutions

Effectively demonstrating a chain of custody is a time-consuming process that takes a large amount of effort and commitment from participating actors. This is further compounded by the lack of standardized CoC platforms, the primitive level of digitization among upstream supply-chain participants, and the need for training on how to deploy supply-chain traceability solutions. While Circulor is trying to automate as much of its solution as possible, Johnson-Poensgen

concedes that he has had to deploy quite a few people to China to help establish rigorous business processes and provide adequate onboarding and training services for supply-chain participants . "Once I've learned to automate as much of this as possible," he said, "I hope to partner with the big consultancies to help clients like car manufacturers and battery manufacturers implement these solutions into their supply chains."[49]

The desire to make the cobalt supply chain more transparent may conflict with the desire for manufacturers and other participants to shield valuable supply-chain information from regulators, competitors, and other stakeholders.

Building the culture and capacity for supply-chain transparency

The desire to make the cobalt supply chain more transparent may conflict with the desire for manufacturers and other participants to shield valuable supply-chain information from regulators, competitors, and other stakeholders. For example, companies may want to keep strategically important information under wraps, including new products under development, unique manufacturing techniques, sources of supply, technical specifications, or their list of customers. Even when there is a corporate predisposition for transparency, companies may lack the skills, tools, and experience to put supply-chain traceability into practice.

University College Dublin researchers found that "many companies have limited visibility into their supply chain information, have a poor understanding of their capabilities for capturing and reporting this information, and have not overtly considered their supply chain information disclosure strategy."[50] However, Johnson-Poensgen argues that the reputational risk faced by consumer-facing companies has created a burning platform for change that is trickling down supply chains. "I feel like we've been pushing at an open door in that people want to participate," he said.[51]

Economizing computing power with an efficient architecture

The large amount of computing power required to run blockchain-enabled CoC systems can create a financial barrier for some countries and smaller suppliers and producers.

The large amount of computing power required to run blockchain-enabled CoC systems can create a financial barrier for some countries and smaller suppliers and producers. Beyond the cost of the required technology are the facilities, staff, transaction fees, data storage, and other operational costs, which can make blockchain solutions financially prohibitive. RCS Global estimates that the costs range from $100 per gigabyte to $50,000 to 100,000 per user.[52] In its work on tantalum, Circulor found that one scan in a mine in Rwanda leads to 900 transactions all through the supply chain.

In working with Volvo, Circulor determined that it would require 300,000 blockchain transactions to map out the production for just 28 cars. When cloud-hosting providers like Oracle charge per transaction, limiting the volume of transactions is a non-trivial task. As Johnson-Poensgen explained, "One of the fundamental challenges we've grappled with is how to create an architecture for the distributed ledger that does not exponentially grow the number of transactions in the network and lead to an overwhelming quantity

of data."[53] To economize on computing power, Circulor is working on aggregating data over a 24-hour period before registering a new transaction on the blockchain.

Key takeaways

Enlist the big consumer brands and the rest will follow.

The supply chain for EV batteries includes a diverse array of companies with differing levels of sophistication and differing priorities based on their exposure to consumer sentiments. These include large industrial cobalt miners like Glencore and Huayou Cobalt; smaller Chinese-owned refiners, smelters, and battery scrap recyclers; battery manufactures such as LG Chem and Samsung; and the ultimate end users of EV batteries, companies such as BMW, Tesla, and Volvo.

Even midstream participants in China understand why their customers want traceability and see their ability to comply with ethical sourcing requirements as an opportunity to gain competitive advantage.

At the outset of its journey, Circulor worried about whether it could attract such a varied cast to comply with its ethical sourcing protocols and to adopt a blockchain-enabled solution. However, Circulor realized that it could achieve effective end-to-end traceability if it engaged the downstream supply-chain members first and worked backward to get each additional tier of the upstream supply chain involved. To launch its traceability solution, Circulor's focused on mobilizing OEMs that needed to be able to demonstrate a socially responsible chain of custody all the way back to the source of the raw material. "I just need to find one or two or three paths from the downstream manufacturer to the upstream producer of the raw material in order to demonstrate the benefits of an effective chain of custody where all the participants are observing ethical sourcing practices," said Johnson-Poensgen.[54] He noted that even midstream participants in China understand why their customers want traceability and see their ability to comply with ethical sourcing requirements as an opportunity to gain competitive advantage.

Track the commodity, not just the documentation.

The focus of many blockchain-enabled supply-chain traceability initiatives is on a creating a chronological record of key supply-chain events and transactions on-chain. They work by capturing the documentation events created by transactions in the end-to-end journey of a given material through the supply chain. While Circulor also captures information about transactions, the company is differentiating its solution for minerals by assigning a unique identity to each secure bag of cobalt material and tracking the material through each subsequent stage of production. In this sense, Circulor's approach resembles Everledger's approach for tracing the provenance of diamonds.

Using machine vision, Everledger records 40 metadata points to create a unique thumbprint of each stone. The diamond's unique physical properties, along with key details such as its place of origin

and chain of custody, are then added to the blockchain, creating an audit trail to make each stone completely traceable. "We believe that if you're trying to demonstrate traceability it's not just about a track and trace of documentation, it is actually about the commodity itself," said Johnson-Poensgen.[55]

"We believe that if you're trying to demonstrate traceability it's not just about a track and trace of documentation, it is actually about the commodity itself."

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Founder
Circulor

Solve the really hard problems to differentiate your traceability solution.

Hosted blockchain services provided by Oracle, AWS, IBM, and others are making it easier than ever to deploy a solution. According to Johnson-Poensgen, getting the blockchain infrastructure up and running represented the most straightforward aspect of Circulor's journey. The harder problems in supply-chain traceability all gravitate around the need to ensure that the data recorded on the blockchain is reliable. Among other things, these problems include mapping the end-to-end supply chain, carefully vetting participants, developing protocols to safeguard the security and veracity of the data, and training personnel on the ground to implement the traceability solution. The ability to address these challenges assuredly is what makes Circulor such a valuable and trusted partner for automakers like BMW and Volvo.

Use ethical sourcing efforts to heighten performance across supply-chain tiers.

Most OEMs have close working relationships with their tier 1 suppliers. Few have a detailed understanding of what's actually going on with their tier 2 suppliers and beyond. Responsible sourcing initiatives are closing this knowledge gap by forcing principal component manufacturers to obtain complete visibility across the supply chain, right down to the tier 5 and 6 suppliers of raw materials. In fact, Johnson-Poensgen recounts how Circulor's pilot project with Volvo was the first occasion in which the automaker had met with its tier 5 suppliers and had a conversation about responsible sourcing and why this was their new route to market.[56] With a blockchain infrastructure providing end-to-end visibility and real-time data, traceability efforts provide a ripe opportunity to get all tiers of the supply chain working together to improve performance.

The one benefit that most intrigues the automakers with whom Circulor is working is the ability to more accurately calculate the carbon generated at each step of the production process.

Harness the digitization of supply chains to exploit ancillary benefits.

The imperative for supply-chain traceability has prompted lead OEMs to help accelerate the digitization of their less advanced suppliers, especially those lacking quality management systems and scan-in/scan-out capabilities. These advances in digitization will have ancillary benefits, such as the ability to pinpoint new efficiencies, speed up payments, and reduce working capital. However, the one benefit that most intrigues the automakers with whom Circulor is working is the ability to more accurately calculate the carbon generated at each step of the production process.

The strategic rationale for EVs, after all, is that they are ultimately better for the planet than their gas-guzzling counterparts. Some car manufacturers such as Daimler have even publicly committed

Going carbon-neutral requires detailed, data-driven insights into the amount of energy and materials used in the manufacturing process.

to being carbon-neutral by 2039. Going carbon-neutral, in turn, requires detailed, data-driven insights into the amount of energy and materials used in the manufacturing process. As Johnson-Poensgen explained, "If you can measure the amount of carbon used at a battery scrap recycler, for example, and you know exactly how much of their output is coming to you, you can start to build a detailed understanding of the total carbon generated at each stage of production."[57]

About the author

Anthony D. Williams is co-founder and president of the DEEP Centre and an internationally recognized authority on the digital revolution, innovation, and creativity in business and society. He is co-author (with Don Tapscott) of the groundbreaking best seller, *Wikinomics: How Mass Collaboration Changes Everything,* and its sequel, *Macrowikinomics: New Solutions for a Connected Planet.* Among other current appointments, Anthony is an expert advisor to the Markle Foundation's *Initiative for America's Economic Future*, a senior fellow with the Lisbon Council in Brussels and the Institute on Governance in Ottawa, and chief advisor to Brazil's Free Education Project, a national strategy to equip two million young Brazilians with the skills required for a 21st century workforce. His work on technology and innovation has been featured in such publications as the *Huffington Post*, *Harvard Business Review,* and the *Globe and Mail*.

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Co-founded in 2017 by Don and Alex Tapscott, the Blockchain Research Institute is an independent, global think tank established to help realize the new promise of the digital economy. For several years now, we have been investigating the transformative and disruptive potential of blockchain technology on business, government, and society.

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