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SPECIAL
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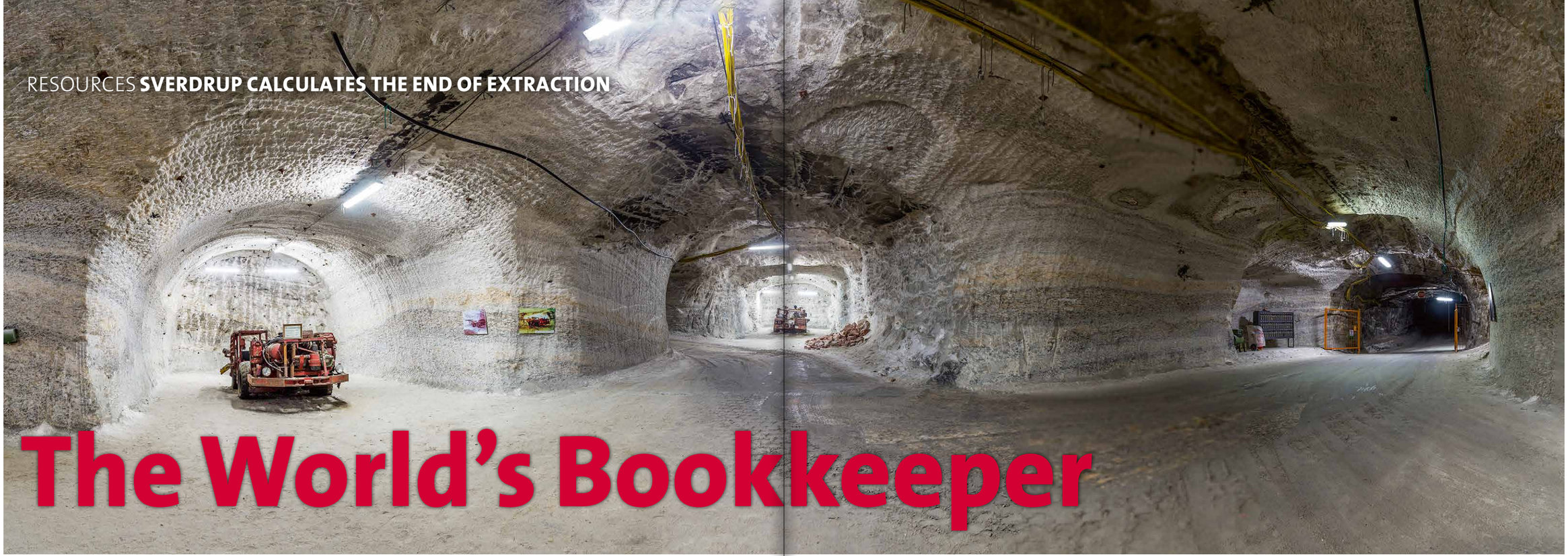
Copper mining will decline from 2044

What remains...

Our final resources



The World's Bookkeeper

He is the World's Bookkeeper. No one knows better what resources remain than the Norwegian professor Harald Sverdrup. His computers calculate what resources are left in the earth's crust, how much we can extract, and even how much we will need in the years to come. What he cannot do, is distribute these final stocks fairly. The last resources should go to those companies that facilitate complete reuse. Who will take on this task?

Who keeps track of our remaining raw materials today? Answering that question is a quest in itself, which ends in Reykjavik, Iceland and in Hamar, in the southeast of Norway, places where Professor Harald Sverdrup (1954) resides. He feeds his computers with data on 67 different resources. How big are these estimated residual extractable stocks? How much do we use? When is the peak in production, after which the supply will decrease? How much of those materials do we recycle? When will everything be gone? Sverdrup's computers churn, while he shows graphs in the lecture halls reminiscent of the curves that are hopeful when it comes to combating the Coronavirus. But the drop in global production in the coming years is by no means something to be happy about. They include ores that are crucial to realise the energy transition. And these materials are already scarce. Sverdrup also shows his students the peak years in production, a concept that marked the peak of crude oil extraction in 2012, and gold in 2016, which has become increasingly expensive since. The production decline for cobalt – for example – is due to start in 2026. Is this an echo of the old message from the Club of Rome, the organisation of critical thinkers who raised the alarm in the previous century to find that there were limits to our economic growth? Absolutely. In fact: Sverdrup and his Icelandic colleague Dr. Anna Olafsdottir are working on the latest integrated assessment model, for a report to the Club of Rome, entitled WORLD7.

He sounds like a modest man, with the same charming English accent that also typifies Norwegian actors in internet series about Vikings. A kind of silent relentlessness that resonates in his analysis of the Corona crisis. Sverdrup: "The world has turned upside down. What was previously true is no longer so. Moreover, what was true is no longer valid. Much has been reversed, which has resulted in an environment in which changes are possible that we previously found uncomfortable or even impossible. Making these changes is in fact our duty. And why not?"
His lists come in handy here. He produced them at the University of Iceland and the Inland Norway University of Applied Sciences. How did he obtain the resource estimates and figures? Sverdrup: "From very smart geologists who use sophisticated geostatistics and prospecting results. As a result of the current production and prospects, we can see how much we will still be able to find in the future."

Do you only use data from independent researchers or also from commercial mining companies?
"It is a mix; in addition to geological literature, I also include all available commercial research and assessments. Mining companies make a very strict difference between geological stocks(deposits) and resources. Geologists know how much is available in the geological formations on Earth but also ask the question: how large is the stock that we can actually access? And: at what price? The latter is important. Although for some minerals, the stocks are very large, it is economically impossible to use them. Sometimes they lie deep under the ocean floor, sometimes beneath large cities. If you would find a large gold supply under the heart of New York City, you wouldn't be able to mine there. You wouldn't even obtain a permit, let alone manage to tear down the Empire State Building. In other cases, the stocks are situated so deep that digging becomes far too expensive. Mining companies therefore write off these resources. We just can't reach them."

Mining companies have a horizon that does not go beyond around twenty years. If you can continue to produce for that duration, shareholders are satisfied.
"They provide figures with a time horizon of five years, ten years and twenty years. But there are also other geological explorations. As intermediaries, these geologists also know what mining companies are looking for."

Like the United States Geological Survey?
"That is one example. But South Africa also has such a research institute. India has one too. Saudi Arabia. The Chinese too, although they do not share much information. The British. The Russians."

And you have all these resources?
"I have collected an incredible amount of this type of information and compiled long, long lists. This gives you a pretty good insight into what can still be found. Then we look at these figures in relation to the price. Like: OK, at this market price there is still so much copper available. But now let's see what happens when you double the prices: how much more copper can you mine in less favourable places? And then triple again. At some point you reach a limit of what is still possible. You will no longer mine copper, no matter how high the copper price."

You often hear the following comment: there are still many residual stocks in this world that have not been found. The planet is so large... Is that true?
"Much has not yet been found physically or legally. On the other hand, when geologists have mapped the ground of two-thirds of a country, then you'll roughly know what that

Professor Harald Sverdrup lectures: "Between 2030 and 2070 we will peak in the extraction of nearly all raw materials. From then on, the supply of natural resources will gradually decrease."

When do world stocks of resources end?

Resources	Applications	Extraction Peak Year	Recycling
Oil	Transport	2012	0%
Gas	Heating, industry	2016	0%
Coal	Heating	2020	0%
Cadmium	Paint dye, batteries	2010	80%
Gold	Jewellery, investment	2016	85%
Cobalt+	Colourant, batteries, gamma rays	2026	40%
Gallium+	Electronics	2026	5%
Silver	Jewellery, industry	2038	70%
Selenium	Vitamins, solar cells	2042	0%
Natural stone	Construction, decoration	2040	20%
Lead	Batteries, electronics, construction	2041	65%
Niobium+	MRI scanners, steel, coins	2045	60%
Tin	Opto-electronics, steel, tin	2046	40%
Antimony+	Lead batteries, fire extinguishers, cosmetics	2048	15%
Indium	Electronics, solder, semiconductors	2042	20%
Rhodium	Catalysts, jewellery	2034	60%
Germanium+	Glass fibre, infrared equipment, solar cells	2042	20%
Bismuth+	Cosmetics, pharmacy (diarrhoea)	2044	5%
Nickel	Coins, stainless steel, magnets	2028	50%
Platinum+	Electrodes, thermometers, chemotherapy	2036	70%
Titanium	Aircraft, glasses, bicycles, watches.	2038	40%
Tellurium	Processed in copper, solar panels	1984	0%
Phosphate+	Matches, fertilisers, fireworks, toothpaste	2035	16%
Palladium	Catalysts, hydrogen cells	2042	60%
Aluminium	Transport, packaging, construction, equipment	2030	75%
Iron	Industry, steel, transport, shipbuilding	2052	60%
Magnesium+	Iron and stainless steel, beer cans	2053	45%
Tantalum+	Electronics, smartphones, PCs, cameras	2035	60%
Molybdenum	Metallurgical industry, defence	2038	40%
Rhenium	Gas turbines, aircraft engines	2042	40%
Uranium	Nuclear energy, defence, glass industry	2035	50%
Zinc	Anti-rust, fencing, roofs, batteries	2046	20%
Chromium	Stainless steel, coating on metal	2051	22%
Copper	Coins, electrical wiring, pipes	2044	60%
Lithium	Batteries, air purification, medicines	2060	10%
Rare Earth+	Electronics, catalysts, magnets	2045	15

+ Are also on the list of "Critical Raw Materials" EU

Source: Harald Sverdrup and Anna Olafsdottir

last stretch contains. It's these kinds of statistics that we and our geologist colleagues are quite good at. We have been doing this for so many years. The Finns have thoroughly researched their country. The Swedes have already mapped half of theirs, but the rest of it has the same geology. The figures are therefore quite reliable. You, in the Netherlands, know the soil very well when it comes to natural gas."

So that is the basis for your calculation of the extraction peak years for so many different resources?
"Production will decrease from that specific year. This doesn't mean all minerals are physically used up. An extraction peak year means: we are running out of stocks that are still economically viable. When the price goes up further, it will eventually destroy the profit-margin of what you can sell the product for. And this is how it works for all metals and other natural resources. We have modelled all these calculations for the report to the Club of Rome. At one point, the earlier model they used was called World3, the basis for The Limits to Growth, the famous report. That warning shocked the world, but the model then described the resources supplies in a very simplified way. That was the only option in 1972, because computers were unable to perform very complex and dynamic calculations. But those computational limitation no longer exists. Today, computers can do everything I ask them to. We have built the new generation of model that can calculate how many materials we will need to make all products. The smartphone I'm holding now, the computer you're behind, the door handles in your house, the cutlery in your kitchen. The current models calculate how many materials we'll need to make all of this. And how much comes back and is recycled. We then see two things. There is an incredible amount of materials in circulation, and we have an increasing number of people achieving a high standard of living. A billion Chinese want the same door handles we have, ten per house. That involves billions of handles and huge quantities of material. We are now in a phase to meet that demand.

South African miners in a platinum mine, one of the essential metals in the energy transition.

But not many of those door handles come back for reuse. We usually throw them away. This linear use is fast and wasteful. We burn through our things very quickly. This leads to an enormous accumulation, and means that we will peak for nearly all raw materials between 2030 and 2070."

When you no longer have certain materials, many other raw materials also become unusable. Take rubber. A car without rubber tires can no longer drive.
"For some technical applications, the materials used are so specific that they cannot be replaced. It means that if you run out of platinum, you can no longer make a complete product such as a catalyst to convert electricity into hydrogen or hydrogen to electricity in a car afterwards. Or it means that when you can't make a product with exotic materials anymore, it weighs 14 kilos instead of 140 grams, making production impossible. When your aircraft is broken and your flight is cancelled, that craft is not immediately replaceable by another: it has already been booked. The potential of substitution that economists would like to see as the rescue, is very limited. It can be applied to niche products, but not to bulk products and very large quantities."

So that makes your list alarming. Especially because the recycling percentages are not very high. Is this about current or future percentages?
"These are today's percentages. Where my list states 30 percent recycling, it means that 70 percent is thrown away. That is not sustainable."

And that means that without a perfect circular economy of 100 percent reuse, the number of available materials will decrease very rapidly. Perhaps most will be gone in 2100?
"There will be major supply problems by then. The generations after 2100 will face serious material shortages. And if they can be extracted anywhere, we will find them in a less pure form than today's stocks. This means that the extraction will cost more energy, in a world that may have less energy to use. Those energy costs are already increasing every year. The number of available sources in our geological stocks is also decreasing year by year. Iron extraction alone will take up 30 percent of the total energy demand on Earth by 2070. That is a lot! What are we going to do then? Are we saying goodbye to the Iron Age? Are we going back to ... what? We simply cannot let it come to that. We must change our ways."

"We must reward companies that include the reusability of raw materials in their design. And we will have to apply some form of punishment to the companies that don't."

The EU uses a different list than you, for critical resources. How is it that there are two entirely different lists? What is the difference between them?
"The difference mainly lies in the timing of the lists. The EU list warns against problems when some materials become unavailable in the short term. I look at the finite nature of the stocks and the longer perspective. So, the lists do not conflict. Indeed, there are materials on the EU list that I have not yet researched. On the other hand, we already provide data that will only be included in the documents in a few years' time due to official processing time by the EU. That's a standard delay. We think it is the long-term calculations that ultimately matter the most. In the short term, there will always be variations and an unstable balance between supply and demand."

The EU list shows which countries extract most raw materials. With a few exceptions, this is always China.
"China has a large amount of natural reserves and uses a large part of them itself. The Chinese also export these materials in the form of processed products. China also imports a lot. As a result of our current short-term policy of outsourcing production to China instead of Europe, we have put ourselves in this position.

When measuring becomes predicting

The Sustainable Finance and Accounting research group at Avans University of Applied Sciences conducts studies to enable countries and organisations to demonstrate their value creation. It is based on six themes. One of those themes is natural capital which, today, mainly shows value destruction. Establishing a global accounting system for natural capital - raw materials, water, biodiversity - will show that a better financial performance via the depletion of natural resources is a financial illusion, and that countries and companies are eroding their ability to create wealth. More money in the bank now leads to poverty in the future.

Research into how companies can include natural capital as an asset on their balance sheet and make depreciation visible in their profit and loss account will show shareholders how their investment capital is eroding. Further research is needed as today's balance sheets don't show investors that it is more attractive to invest in circular companies. These sustainably driven organisations are not exhausted as they reuse natural capital and thus retain their value.

Website **Sustainable Finance and Accounting of AVANS University of Applied Sciences**

What is on the EU's list of "Critical Raw Materials"?

Minerals	Largest source of	Input recycling
Baryte	China 44%	1%
Beryllium	US 90%	0%
Borate	Turkey 38%	0%
Coking coal	China 54%	0%
Fluorspar	China 64%	1%
Hafnium	France 43%	1%
Helium	US 73%	1%
Indium	China 57%	0%
Natural graphite	China 69%	3%
Natural rubber	Thailand 32%	1%
Phosphorus	China 58%	0%
Scandium	China 66%	0%
Silicon metal	China 61%	0%
Tungsten	China 84%	42%
Vanadium	China 53%	44%

Source: The EU list is from 2017

The peak year in oil extraction is already behind us: it was in 2012.

I spoke to an entrepreneur from England. He wondered: where is the British pump factory I inherited? Production is performed in China, assembly in India, design in Pakistan, and invoicing in Spain. Is this still a British company? Bizarre. We have become very vulnerable."

You are like the world's bookkeeper of what remains. But accountants also advise their clients to diversify their expenditures and investments. Should there be a world bookkeeper who distributes the remaining stocks? The final metals only go to those companies that use them to make products from which those raw materials can be removed after use? And the ones who don't, simply don't receive any?

"We have to step away from the present mindset. We must reward companies that include the reusability of raw materials in their design. And we will have to apply some form of punishment to the companies that don't."

But who is going to do this job? Which government or organisation has the power to implement this distribution worldwide?

"Such an approach requires governance, so it has to come from governments; an EU or a national government, as there is no global government. The United Nations can only make recommendations. There is an International Resource Panel, but it is struggling with lack of funding and has been politicised. So not much happens there. We need efficient international institutions."

Which are not there yet. And governments have no policy in this area.

"Very little, but it can be found. The Chinese have a strong raw materials policy. India too, but the implementation is not very efficient. The Russians have a policy, but it is in the hands of the military. In the United States, the government does not have a policy, but the army does. It is a very fragmented image. Many countries don't even think about it. Some countries had strategic supplies but sold them. The Americans privatised their helium reserves, and started selling it off. They also disposed of their Rare Earth stocks, very important for the ongoing renewable energy transition. Higher government debts make it seem favourable to monetise products, and finance short term costs. The Russians lost much of their resources in the chaotic years after the fall of the Wall and the communist dictatorship. The proceeds filled many holes and pockets to steal from. All kinds of motivations to sell to anyone who was interested."

But in Europe we don't have a resources strategy?

"The Germans are working on it. This is a total strategy. Where do we get our resources from? Who has these materials? How do we create efficient use within our own national system? How much service do we get from every kilo of raw material and how do we maintain this level?"

So Germany is ahead of the EU?

"Germany has done many studies on the *Energiewende*, the transition to renewable energy sources. Harry Lehmann at the German Environmental Protection Agency was the mastermind behind it. He realised that an *Energiewende* also included a *Resourcewende*. To realise the turnaround, Germany needs all those critical materials to be able to build the right technology at the right time. But a *Socialwende* is also needed, in which our behaviour changes, our business, our society. It will not make our life unpleasant, but it will be a little bit different."

Will the Corona crisis help us understand that we need to change our behaviour and settle for fewer possessions?

"I think this viral crisis will quickly continue into a strong economic crisis. We should take this opportunity to think in new dimensions. How are we going to continue?" ■

Harald Sverdrup is expected to be in the Netherlands on September 6, as one the speakers during a conference organised by Wouter van Dieren in the church of Broek in Waterland. During this meeting an international group of thinkers will continue to work on the next WORLD7 Club of Rome report.

Websites

+ **246 studies of prof. Harald Sverdrup**
+ **EU website on "critical raw materials"**

+ Text Marleen Janssen Groesbeek and Jan Bom
+ Editing Akke Pinkster
+ Photography Dreamstime
+ Art direction Bureau Boudewijn Boer en Studio 10
+ Atticus bv
+ www.p-plus.nl

In preparation for this interview, we spoke to Wouter van Dieren (Club of Rome), Ralph Thurm (r3.0, www.r3-0.org) Benjamin Sprecher (Leiden University), Gert Jan Kramer (Utrecht University), Sybren Bosch (Copper8) and Elmer Rietveld (TNO).