Harvesting the Rare Earth

Art-science research, reflections and discussion

Draft version March 2017

Martin Malthe Borch
Jacob Remin

Jacob Remin: jacob@sciencefriction.dk
Martin M Borch: mmborch@gmail.com, @mmborch

Harvesting the Rare Earth

An interdisciplinary art-science exhibition and near-future speculative installation.
An exhibition at Overgaden Institute of Contemporary Art in Copenhagen from the 27th of January until March 2017. This exhibition text have been made by Jacob Remin and Martin Malthe Borch.

http://overgaden.org/udstilling/jacob-remin-harvesting-the-rare-earth/

This text collects the preliminary scientific literature research. Following presenting the art-science reflections and the technological potentials of the suggested exhibition.

This text is not a scientific peer-reviewed paper and should not be read as such. Some of the references are review articles, and not primary literature.

Content

Abstract and Aim

Introduction

In *Harvesting the Rare Earth* we present a hypothetical scenario of the near future in which biotech companies have developed a method enabling genetically modified caterpillars to harvest Rare Earth Metals from e-waste dumps around the world. The exhibition uses the exchange between actual and hypothetical issues to investigate the power structures of the world in an exhibition that focuses on the environmental and human consequences of our consumption and addiction to technology. Harvesting the Rare Earth contains the showroom and test laboratory of the bio tech company "Hybrid Ventures" that have developed the biomining technology. Hybrid Ventures have used genetic engineering to develop their technology, where one of the latest methods developed to do genetic engineering is called CRISPR/cas9 or just CRISPR. This technology and the way it is used analysing genetic sequences with computers, have highlighted the trend that the border between computers, electronics and biology is blurring. CRISPR, and other technologies, have already been applied to genetically modify microorganisms, insects, animals, humans and the currently it's being discussed if entire ecosystems can be modified and genetically engineered.

Aim:

The aim of the exhibition is to explore the environmental and human consequences of our consumption and addiction to technology, be it biological or computers and electronics. It investigates the scales, relations and power structures between insects, resources, geology, planet and humans. The exhibition gives a concrete appearance to our relation with the information society, e-waste and the potential applications of CRISPR in relation to hybrid ecologies, and serves as a catalyzer for reflection and discussion.

With microorganisms and algorithms gaining more agency in our lives, the borders of the human self is up for discussion. We are seeing the rising development of numerous ways that cells and data interact across species and systems, creating complex hybrid ecologies and challenging our traditional understanding of the world centered around man. One of the main questions is: "What is happening with our understanding of the relation between nature, human and technology?"

We hope that the reactions and discussions will be valuable understand public and individual opinions, not least the opinion of companies, university researchers and bioethicists.

Reflections and reactions will be collected in connection to a seminar about the exhibition the 24. Feb 2017, and through general input and feedback.

Starting Point

The starting point was Jacobs earlier work in connection to the large e-waste dump at Agbogbloshie, in Accra, Ghana. Harvesting the REE from the e-waste dump with butterflies would create a parallel to the hard human conditions of extraction the REE from the primary mines in the first place. Secondly the idea evolved to develop a company with a business model centered around biological mining, and the reflections on the aesthetics of such a company. This in turns lead to reflections about the actual possibility of designing and engineering such a solution. The point of researching the scientific support and potential of the idea was two fold. A) to create an as realistic exhibition as possible, or at least realistic to a level where the technology presented would sound plausible for the general citizen and hence not take up so much attention that it would take over the personal reflections, and not let the visitor rest in the immediate emotional experience of the exhibition. Secondly B) Through researching the actual scientific potential and possibilities the exhibition could serve as a starting point for scientific discussion and science communication. Both among scientist, that would be presented potential implications and applications of their research, and among the citizen being presented the possibilities with contemporary technology.

The technology we developed is presented in the exhibition through a speak by Hybrid Ventures:

Hybrid Ventrures: The Butterfly Solution™ [speak transcript]

It is impossible to imagine our current society without Rare Earth Elements. The electrochemical properties of these 17 elements are driving technology development in the 21st century: From lasers and fiber optics, to rechargeable batteries, harddrives and screens. Our cloud based, digital existence is closely connected to the earth.

In 2012 the global demand for Rare Earth Elements was 140,000 tonnes, in 2013 160,000 tonnes, in 2014 180,000 and in 2015 200.000 tonnes. The trend is continuing, and with most of the world's current production of Rare Earth Elements on chinese hands, we will face a 21st century supply crisis, similar to that of fossil fuels, if we don't act fast and secure alternative supplies already today.

At Hybrid Ventures we are thrilled to present our newest innovation and the global launch of sustainable biological mining. We have successfully engineered a hybrid ecosystem around the e-waste dump of Agbogbloshie, in Accra, Ghana. We call it The Butterfly Solution . Through minimal genetic intervention we make it possible to recollect and remediate the rare earth elements that can be found in cast-away electronics, effectively re-using the resources of the rare earth in several product life cycles.

Agbogbloshie in Ghana is the world's largest e-waste dump. The area, localized centrally in Ghana's capital Accra, covers around 3.000 m2. Roughly 40.000 people live in this area disassembling, re-working, and re-using electronic and metallic resources from around Ghana and the world. Locals are using hammers and brute force to take apart machines, scavenging for precious metals and private data. Unused parts are burned on site, covering the area in a constant toxic haze. The chemical pollution from Agbogbloshie runs thick, into the river of the Korle Lagoon and on into the Atlantic Ocean.

It is estimated that at least 172,000 tonnes of e-waste pass through Agbogbloshie every year. With the full implementation of our patented Butterfly Solution , we plan to harvest 10,000 tonnes of Rare Earth Elements per year. Enough to supply 50% of the predicted yearly increase in global demand. All of this done, greener, cleaner, and more efficiently.

The Hybrid Ventures Butterfly Solution is a hybrid ecosystem, consisting of 3 elements: A nutrient and chemical solution, an engineered fungi and a butterfly of the species Morphu Hephaestus.

The application of the Butterfly Solution is simple:

The nutrient solution is spread over the area. Chemicals from the solution slowly dissolve the Rare Earth Elements present in the electronic components of the e-waste. The microscopic fungi feed of the nutrients in the solution and accumulate Rare Earth Elements in their cell tissue.

The butterflies, at this point in their larval state, feed off the fungi and nutrient solution. Once ready, the larvae pupate and turn into butterflies saturated with Rare Earth Elements.

Butterflies are naturally attracted to light on the border of the ultraviolet spectrum, and so ultraviolet light beacons are placed in connection with the e-waste field. The beacons make for convenient harvest points.

Once collected, the butterflies are put in an enzymatic acid solution that dissolves the organic matter of the butterfly. Rare Earth Elements are mechanically separated into clean mineral fractions, ready for industrial application, and the organic matter is returned to the nutrient solution to be recycled.

Hybrid Ventures is honored and thrilled to present our technology and research experiments here at this wonderful location. The great history of clean and innovative biotech has always been a source of inspiration for Hybrid Ventures, and so sharing our ideas and innovations with a wider audience like this, gives us great pleasure.

We are currently in collaboration with authorities in China, India, and South America about other potential sites to be mined biologically. And we are starting to collaborate with mining *companies to develop solutions for their mining waste, the large piles of ore and the lakes with process water.*

We are always looking for potential future employees and partners. If you want to collaborate or work with us, do get in touch.

The Solution, the speculative design

To design the Hybrid Ventures - Butterfly solution, we needed to address and research various challenges and issues, that lead to the final speculative design. Come of these questions were how could we...

A. Break down the e-waste into smaller parts.
B. Dissolve the chips, metals and alloys to enable the ions to be taken up by the organisms.
C. Enable the insects to concentrate the minerals in the tissue.
D. Collect the insects.
E. Extract the REE from the insects.

The solution that we have designed contain the following 3 elements.

1. A nutrient and chemical solution.
2. An engineered fungi
3. An engineered insect to carry the RRE. (Beetle of butterfly)

Breaking down the electronic waste
Breaking down the electronic waste is done on site by the people already working there. The parts that can be reused or resold are removed. The leftovers ends up in big piles or are burned. We assume this is sufficient degradation to make the leftover minerals available. Though the burning process might oxidize minerals and make them chemically inert and not reactive.

Nutrient Solution
The nutrient solution is spread on the area that we are mining. The solutions contains:

- Water as a solvent for the REE, and is essential for the fungi and insects to survive.
- Fungal and bacterial spores.
- Nutrients for the microorganisms to grow, as they cannot live of the minerals they take up, they need a carbon source, eg sugars.
- Chemicals that help to dissolve and ionise the REE as acids, buffers and ligands.

Dissolving metals
Several natural bacterial and fungal species have been found that can dissolve a long range of metals as Ag, Al, Cu, Fe, Mn, Pb, Zn, Ti, Mo and more.

Harvesting metal with insects
In this exhibition we suggest that to harvest the REE with a butterfly due to the aesthetic value and the cultural connotations. Further some butterflies are attracted to the ultraviolet

spectrum of light and can thus be collected using "normal" insect collectors, which aesthetic is familiar to the audience.

Binding the metal inside the insect
We suggest that the functionality from the fungi and bacteria to collect metal are engineered into the insect. We imagine a combination of metal binding proteins, the creation of vacuoles that concentrate the metal ions inside the cell. We also suggest that we can introduce natural chemical reactions into the insects that can precipitate the metal ions inside the vacuoles or directly inside the cell tissue.

Extracting the metal
The REE are extracted from the butterflies through an enzymatic treatment that dissolves the organic matter of the butterfly. This makes it possible to collect the metal particles through sedimentation, and return the dissolved butterflies, thus the nutrients, back into the system via the nutrient solution.

Background Research

Literature study on bioremediation and biomining of Rare Earth Elements. A more in depth scientific and technical presentation of the hybrid ventures technology and underlying research.

Fungi dissolving metals and rocks

Over 80% of all land plants form some type of symbiotic association with fungi. This class of fungi is called mycorrhizal fungi. A subgroups of these symbiotic relations are so close that the fungi actually grows inside, or among the root cells of the trees and the plants. This sub groups is called Ectomycorrhizal fungi. This symbiotic subgroup is restricted to <5% of terrestrial plant species[1]. The fungi colonies in these symbioses have been found to dissolve rock minerals and exchange them with the trees and plants. The fungal hyphae actually create small channels in the minerals of about 0,5-2 µm. By excreting organic acids as oxalate, citrate and malate, and phenolic compounds, protons and siderophores[1]. The same capability have been found for fungi living symbiotically in lichen.

[1] Landeweert et. el 2001 - "Linking plants to rocks:ectomycorrhizal fungi mobilize nutrients from minerals"

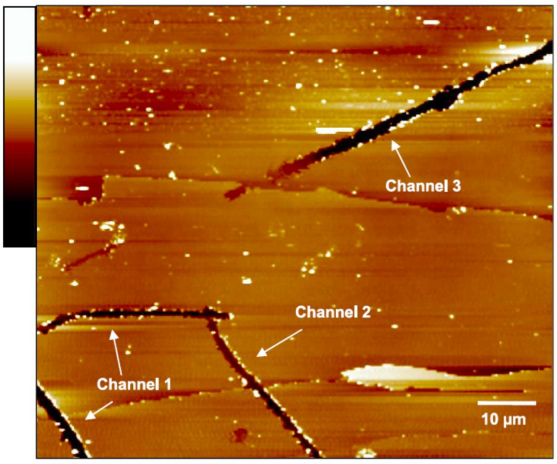


Figure from Gazzé et. at.[2] *A chlorite area displaying the typical channels produced on the chlorite surface after colonization by hyphae. The Z-height scale is 0–30 nm.*

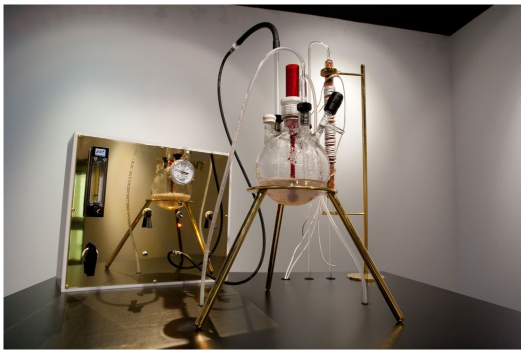
Non-symbiotic fungi bioleaching, thus fungi growing alone and not in association with plant roots, have been tested on municipal solid waste flyash, dissolving metals as Al, Cu, Fe, Mn, Pb, Zn. The species used was *A. Niger* and it was cultivated in a liquid medium with up to 4% w/v fly ash. At a 1% w/v ration, 80–100% of the Al, Mn and Zn was dissolved, 60–70% of the Cu and Pb and about 30% of the iron Fe. [3]

Harvesting gold with bacteria

Also bacterial species have been found to dissolve metal. *Chromobacterium violaceum* and *Pseudomonas fluorescens* were used to produce cyanide ions to form water soluble gold cyanide from electronic waste . The maximum gold concentration of 3.7 mg L-1 was obtained at 2% pulp density of electronic scrap material. Bacterial species as *Acidithiobacillus ferrooxidans* have also been used to improve gold cyanidation extraction processes. [4]

But bacterial species can also turn the dissolved metal back into solid metal. The Artist Adam Brown have created an installation with the bacteria Cupriavidus metallidurans, it can grow on massive concentrations of dissolved gold chloride AuCl3 a toxic chemical compound found in nature, and turn it into usable solid 24K gold.[5] [6]

[2] (Gazzé et. al. 2012) "Nanoscale channels on ectomycorrhizal-colonized chlorite: Evidence for plant-driven fungal dissolution". J. of geophysics research.
[3] Wu and Ting 2004 - Metal extraction from municipal solid waste (MSW) incinerator fly ash—Chemical leaching and fungal bioleaching.
[4] Ramakrishnan B (2016) Bioremediation with Simultaneous Recovery and Reuse of Resources. J Bioremediat Biodegrad.
[5] http://msutoday.msu.edu/news/2012/gold-loving-bacteria-show-superman-strength/
[6] http://adamwbrown.net/projects-2/the-great-work-of-the-metal-lover/

Gold nuggets produced from bacteria and a the bioreactor where the bacteria was cultivated. Images from the exhibition "The Great Work of the Metal Lover" By Adam W Brown.

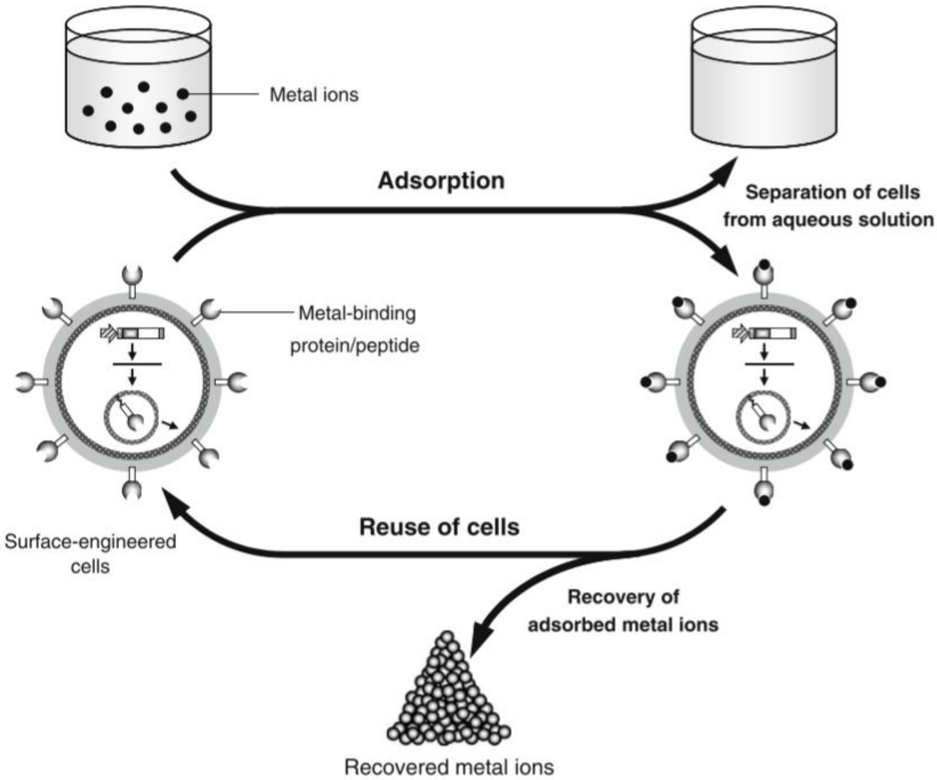
Collecting solid metal in insect tissue with metal binding proteins

To collect the metal it needs to be concentrated, mineralised, and transported from the ewaste-soil with fungi to a place where it can be collected. Fungi and bacterial species that are naturally present in areas with high amount of REE minerals have developed a mechanism to limit the toxic effect of the ions in the environment where they are living. Metal in ion form and in water solution is more reactive, and hence more toxic to the microorganisms. To minimise this toxic effect both bacteria have been found to have surface proteins (proteins in their outer cell wall) as a defense mechanism that binds the metal ions, thus inhibiting the reactivity and toxic effect of the ions in their immediate growth environment. [7] There are several suggestions in the literature to use this property for biomining with both fungi and bacteria.

Bacterial mining

Due to the surface proteins that bind and mineralise metal ions, a recent paper propose a biomining method where bacterials cells are used to harvest the metal ions

[7] Engineering of microorganisms towards recovery of rare metal ions.



System for adsorption and recovery of metal ions by adsorption on microbial cell surface proteins. (Kuroda and Ueda 2010)

Further the same scientist propose to develop novel metal binding proteins through screening and engineering.[8] In this proposed method the proteins are binding the ions, where after they are released into another solution, but doesn't materialize and become solid. There suggestion is based on normal baker's yeast harvesting molybdenum.

Harveting Selenium（Se）& Tellurium（Te）with yeast

A research group in Japan have conducted pilot plant studies with the aim of reducing selenium (se) and Tellurium (te) ions and precipitating them from wastewater. They isolated wild type organisms and also tested with *Pseudomonas Stutzeri, Stenotrophomonas maltophilia* and *Ochrobactrum anthropi*.[9]

Storing metals inside the cell

A fungi of the species *Trichoderma asperellum* have been found not only to bind and store metal ions in the cell wall but also to bind metal ions inside the cell. The fungi does this by creating small bubbles (vacuolar compartmentalization) containing the toxic metal ions thus increasing both the resistance towards the metal ions, and the total amount of metal that can be stored inside the cell. When the cell wall binding sites reach saturation, the intracellular metals are transported to the vacuoles and then chelated with citric, malic, oxalic, and other organic

[8] Kuroda and Ueda 2010 - "Engineering of microorganisms towards recovery of rare metal ions"
[9] Satoshi SODA and Mitsuo YAMASHITA, presentation at JUNBA 2009. January 13, 2009

acids to achieve metal compartmentalization. In this way the fungi species can naturally accumulate up to 7,2 g/kg dry-biomass of thallium, when exposed to concentration of thallium of 1000-1500 ug/L medium. The tolerant fungal culture was incubated in a 250-mL conical flask containing 75 mL potato dextrose (PD) broth at 26 °C for 6 days on a rotary shaker (150 rpm) [10]. These Thallium concentrations are quite high, when compared to the highest concentration found in a study of 112 different Polish mining location of 52 mg thallium/kg raw ore.[11]

Weight and carry load of butterflies
Weight from 0,04 - 0,3 gram the largest in the world maybe 2-3 g.
Monarch 10cm span weight from 0,3g - 0,75 g [12]
Morpho species in general. 7,5 - 20 cm span.
Life time of the butterfly life stage is in general 2-6 weeks.

Concentration and Toxicity of rare earth elements to fungi
(Sun et. al. 2015)
Thallium : 204.4 g/mol.
Thallium concentrations above 1000mg/L only very little growth is seen, this is equal to 5 mmol. The concentration in the growth environment is very much dependent on the local microenvironment, and how much metal that is dissolved.

Discussion and Reflections

Larvae, beetle, butterfly or cockroach

What animal or insect should you actually choose for this type of biomining ? First of all butterflies are not well suited as they are very light and cannot carry a lot weight besides their own. It would be better to use a large beetle or cockroach as they can carry more weight and are more robust on many parameters. No matter what insect is chosen, it's an advantage with the activity of larvae or beetles in the topsoil layer as they would mix the soil, nutrients solution and fungi around, and increase the ion and mineralisation turnover making more metal overall available[13].

Cockroaches don't have a larvae life state but hatch from eg into a nymph, while some beetle species have a larvae life state. If the metal is collected in the larvae, either precipitated or ligated in vesicles, will it then be lost during the transformation into an adult beetle? On the other hand, having a larvae life state could ensure that the insects continues to concentrate the metals until it's fully developed. Beetles can be collected by using pheromones or other natural mating signals to attract the insects to sites where they could be collected.

---

[10] (Sun. et. al. 2015) Biosorption and bioaccumulation of thallium by thallium-tolerant fungal isolates
[11] Thallium in mineral resources extracted in Poland, I. Bojakowska and A. Paulo (2013)
[12] https://www.learner.org/jnorth/search/MonarchNotes1.html#1
[13] Effect of earthworms (Eisenia fetida) on the fractionation and bioavailability of rare earth elements in nine Chinese soils

Unanswered questions - Can you actually do this?

Probably yes, but will it be stable? and will it be economically viable? The short answer is probably not, but we don't know, and there is a lot of other unanswered questions that we did not look into. Some of them are:

- What is the total amount of valuable metals in the soil of Agbogbloshie, and hence what is the income potential?
- Would it work in areas with big strip-mine activity ? more likely.
- Can you actually precipitate clean metal fractions inside the insects, by adding various catalytic proteins and modifying natural chemical equilibriums inside the vesicles ?
- Soil and water analysis. What is actually in the soil and the water running through Agbogbloshie?
- When e-waste is burned how do the metal alloy and REE then react? are there created chemical inert compositions that cannot be readily available for degradation?
- Can the fungi species actually dissolve all the REE containing alloys as easily as it dissolves other chlorite rock minerals?
- Toxicity of REE ions. what concentration can the fungi and the insect handle?
- How much nutrient water will you need to create an appropriate growth environment for fungi and insects, and which chemicals would it contain?
- How many insects would you need to collect 1 kg of metal?
- What would happen to all the people working there? Will the land be owned by the company extracting minerals? Or would they live on as they do now?
- Speed and growth rates are natural limiting factors. How fast does the fungi grow and spread over the area? How long time does it take for a beetle or cockroach to fully mature?

Discussion

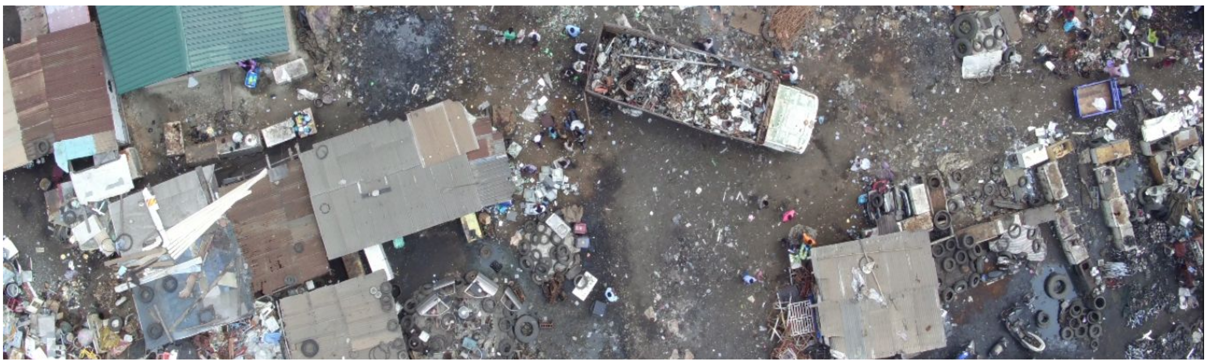
The solution and technology presented here on behalf of Hybrid Ventures is an extension of two central paradigms. First that biology is technology that we can work with, as we work with electronics or mechanics, and secondly that technology always can be used to find a solution, thus there is a "technofix" that can solve the problems that we as humans have in term of our self, our own health, or have created for the ecosphere. The ewaste dump can be viewed as both containing human scale issues, environmental issues and an unexploited resource potential.

Biological machines and forcing a biological systems

Biology is dynamically, organisms will evolve and develop as they shift through generations. This will also be the case of the fungi and the insects in this solution. As the organism live there the genetic modifications will slowly disappear. They will be bred out, as they don't contain an advantage for the organism itself, but only for the humans using the organism. You will constantly need to spray out new engineered fungi and insects on the waste dump to ensure that organisms with the desired trait is present. Further the fungi that mutate and lose the genetic modification might actually survive better, grow faster, and with time outnumber the modified ones. Also as water is added new organisms will start to live at the waste dump. Some might be naturally better suited for that ecological niche, than the engineered organisms, and again grow faster and outcompete the engineered species. Lastly the wild organisms appearing might take up some of the engineered genes that they need to be more resistant to some of the toxic metal ions present.

Ecosystem design

An ecosystem or life in a biological niche is extremely complex, and there are many different mechanisms going on at the same time. Thus there are a set of ecosystem design principles and guidelines that will be present due to the underlying nature of the biological system, and the chemistry and physics it contains. This is in contrast to a solution developed in “dead matter”. A humancentric developed technological solution usually is linear and have one purpose, here to harvest metal. Such a technofix scenario is possible with biology, but as biology is dynamic the solution developed, thus the organism will change, and you will have to constantly add energy or force into the system to obtain the steady state you want. A biological system in balance, that seems to be steady is actually steady due to very complex underlying states that is in constant variation. This can be difficult to design top down but can be evolved. A classical approach is called directed evolution. Here you “co-create” with nature, and create a space, an opportunity space, where the biology can itself evolve into. In this example just adding water and nutrient to the soil will undoubtedly ensure that a lot of new organisms will emerge at the location. You can then help this process, by adding genes to some of them, or in other ways collaborate, and maybe you can harvest the metals from some of the organisms. Thus “biology will find a way.” This phenomenon is clear from a recent discovery that a fungi inside the chernobyl reactor is living and doing well, it is living from the large amount of radiation, and it has no competition inside the olde reactor building.



Agbogbloshie e-waste dump in Ghana, video still, Jacob Remin, 2016

Appendix

Glossary

Bioaccumulation

Bioaccumulation is an active metabolic process driven by energy from a living organism and requires respiration

Biosorption
Biosorption is a metabolically passive process. It's a physiochemical process that occurs naturally in certain biomass which allows it to passively concentrate and bind contaminants onto its cellular structure

Endomycorrhizal
Endomycorrhizal fungi (more commonly referred to as endomycorrhizae) is one of the major types of known mycorrhizae which differs from the another type of mycorrhizae, ectomycorrhizae, in structure. Unlike ectomycorrhizae which form a system of hyphae that grow around the cells of the root, the hyphae of the endomycorrhizae not only grow inside the root of the plant but penetrate the root cell walls and become enclosed in the cell membrane as well (1). This makes for a more invasive symbiotic relationship between the fungi and the plant. The penetrating hyphae create a greater contact surface area between the hyphae of the fungi and the plant. This heightened contact facilitates a greater transfer of nutrients between the two.

The intracellular bioconcentration factor (BCF)
BCF is defined as the ratio of an element concentration in an organism to its concentration in culture, and is employed to evaluate an organism's ability to accumulate the element.[14]

Metallothioneins
Metal binding proteins.

Mycorrhiza
A mycorrhiza is a symbiotic association composed of a fungus and roots of a vascular plant.

E-waste metal concentration.

Urban Mining Potential

Metal	Primary Mining	Urban Mining	Concentration difference
Gold (1)	5 grams/ton in ore	200-250 grams/ton in PC PWBs	40 -
		300-350 grams/ton in cell phones	- 70
Copper	4,5-9 grams/ton in ore (2)	113-131 grams/ton in cell phones (3)	13-26

(1) Umicore. "Technology" metals scarcity and Umicore's offering. Second Quarter 2011. Presentation.
(2) Copper concentration in ore range from 0.5 to 1.0%. Source: http://www.epa.gov/rpdweb00/tenorm/copper.html.
(3) Based on the fact that one million cell phones can recover 9,000 kg of copper.
From: Jennifer Namias 2013. MS Thesis "THE FUTURE OF ELECTRONIC WASTE RECYCLING IN THE UNITED STATES": Obstacles and Domestic Solutions

[14] (Olguín and Sánchez-Galván 2012).

Content of PC waste:

The content of a stationary PC incl. Screen. Weight 27 kg. 1996.
Taken from: http://ewasteguide.info/node/220 (20 feb 2017)
Source: Source: Microelectronics and Computer Technology Corporation (MCC). 1996.

Material name	Content (% of total weight)	Use	Location
Silica	24.8803	Glass, solid state devices	CRT,PWB
Plastics	22.9907	Insulation	Cable, Housing
Iron	20.4712	Structural, Magnetivity	Housing,CRTs, PWBs
Aluminum	14.1723	Structural, Conductivity	Housing, CRT, PWB, connectors
Copper	6.9287	Conductivity	CRTs, PWBs, connectors
Lead	6.2988	Metal joining	Funnel glass in CRTs, PWB
Zinc	2.2046	Battery, Phosphor emitter	PWB, CRT
Tin	1.0078	Metal joining	PWBs, CRTs
Nickel	0.8503	Structural, Magnetivity	Housing, CRT, PWB
Barium	0.0315		Panel glass in CRTs
Manganese	0.0315	Structural, Magnetivity	Housing, CRT, PWB
Silver	0.0189	Conductivity	Conductivity/PWB, connectors
Tantalum	0.0157	Capacitor	Capacitors/PWB, power supply
Beryllium	0.0157	Thermal Conductivity	PWB, connectors
Titanium	0.0157	Pigment, alloying agent	Housing
Cobalt	0.0157	Structural, Magnetivity	Housing, CRT, PWB
Antinomy	0.0094	Diodes	Housing, PWB, CRT
Cadmium	0.0094	Battery, blue-green Phosphor emitter	Housing, PWB, CRT
Bismuth	0.0063	Wetting agent in thick film	PWB
Chromium	0.0063	Decorative, Hardner	Housing
Mercury	0.0022	Batteries, switches	Housing, PWB
Germanium	0.0016	Semiconductor	PWBs
Indium	0.0016	Transistor, rectifier	PWB
Gold	0.0016	Connectivity, Conductivity	Connectivity, conductivity/PWB, connectors
Ruthenium	0.0016	Resistive circuit	PWB
Selenium	0.0016	Rectifiers	rectifiers/PWB
Gallium	0.0013	Semiconductor	PWBs

Arsenic	0.0013	Doping agent in transistors	PWB
Palladium	0.0003	Connectivity, Conductivity	PWB, connectors
Vanadium	0.0002	Red Phosphor emitter	CRT
Europium	0.0002	Phosphor activator	PWB
Niobium	0.0002	Welding	Housing
Yttrium	0.0002	Red Phosphor emitter	CRT
Terbium	0	Green phosphor activator, dopant	CRT, PWB
Rhodium	0	Thick film conductor	PWB
Platinum	0	Thick film conductor	PWB

Team and contributors and acknowledgements

Jacob Remin
Artist, Design Engineer, Interaction Designer.
jacob@sciencefriction.dk
+45 29723927
www.jacobsikkerremin.com

Jacob Remin is an artist based in Copenhagen, Denmark. He is part of the critical new media collective Science Friction and founder of the project space Kommunal Kunst og Teknik.

His practice is a critical and poetic meditation over technology as material, often manifested as physical works in the meeting between light, space, composition and interaction.

Jacob Remin has exhibited and performed numerous times locally and internationally, amongst others at SMK, Kunsthal DIAS, Nikolaj Kunsthal, Transmediale, Ars Electronica, Charlottenborg.

Martin Malthe Borch
Biological Engineer, Interaction Designer, Management consultant.
Associate consultant SPARKCPH, Boardmember REBBLS, Co-founder Biologigaragen.
@mmborch
MB@sparkcph.dk
+45 61713656
www.mmborch.dk
https://dk.linkedin.com/in/mmborch

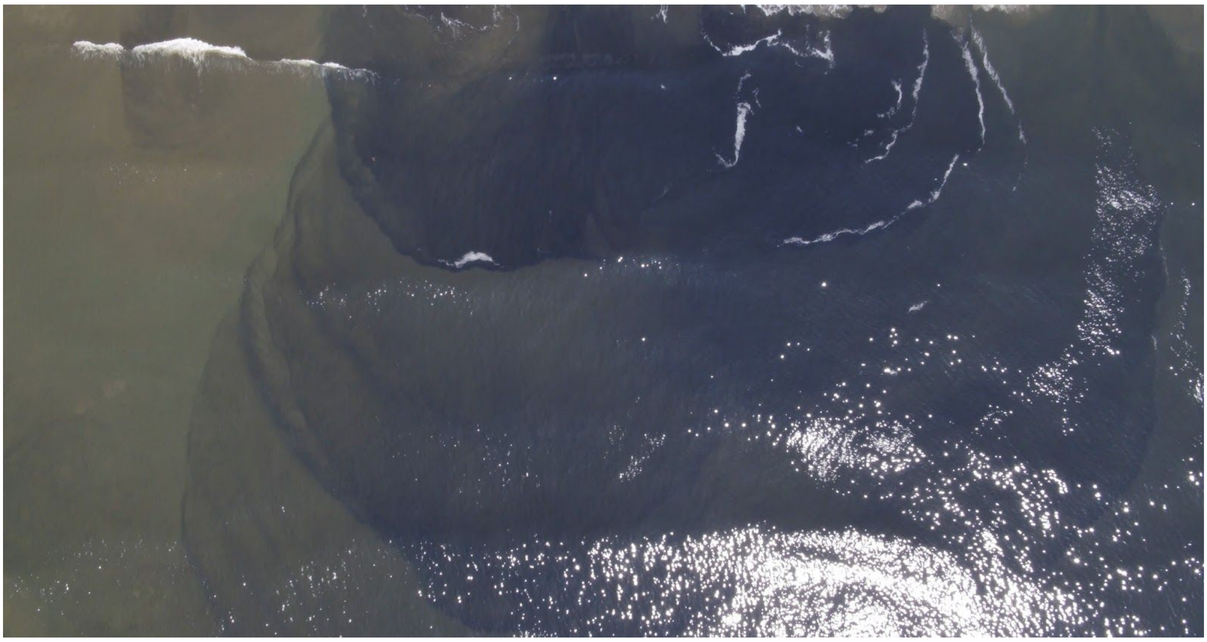
Martin is a management consultant, biotech engineer, designer and artist. As a management consultant he is working with agile project management, design thinking and product and service development mainly within biotech, pharma, life science and sustainability. He holds a master in biological engineering from the Technical University of Denmark (DTU) and a master in interaction design from Copenhagen Institute of Interaction Design (CIID). He co-founded the Copenhagen biohacker space Biologigaragen.

He has appeared in newspapers, museum, magazines, peer-reviewed articles and in documentaries about open science, diybio, biohacking, maker culture, citizen science and open R&D, where his ideas, concepts and thoughts often are described as “game changing” “disruptive” or as “a new paradigm”

Visual Reference Material

Agbogbloshie e-waste dump in Ghana, video still, Jacob Remin, 2016

Agbogbloshie e-waste dump in Ghana, video still, Jacob Remin, 2016



The outlet of the river running through Agbobgloshie, video still, Jacob Remin, 2016