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Review paper
ISSN 0351-9465, E-ISSN 2466-2585
UDC:620.21
doi: 10.5937/ZasMat1802249H

Zastita Materijala 59 (2)
249 - 255 (2018)

Raw materials in future: some novel sources?

ABSTRACT

A survey is given on the present status of raw materials reserves, trends in consumption rate, etc. The raw materials are further depleting and crisis in supply is possible in future. The components of the supply/consumption complex are identified and analyzed in an attempt to get closer in balancing them.

Approach was accepted not to limit the possible sources of raw materials. Some extraordinary sources were considered, as e.g., exploitation of metals from the Earths deep interior and of planet Mars. No matter that the feasibility of such processes in near future is with low chances, one should keep them in mind as one of the promises of new technologies.

Another, quite futuristic chance was selected and analyzed. Space mining, the subject of past dreams, seems to get closer to its birth. The asteroid 16 Psyche, is declared to provide iron supply for 'several million of years' (!?), and activities are in course to get prepared for accepting such a gift from the sky. Varieties of exploitation possibilities, parameters of space mining, costs, property and other economy related aspects are already considered. The most distinctive characteristic of this asteroid is that it is free of crust, i.e. only metallic core does exists, so that there is no non-metallic layer of burden to be removed when exploiting it.

Keywords: *raw materials, sources, traditional vs. new (revolutionary new), space mining (?)*

1. INTRODUCTION

This paper is somehow continuation of my paper published in this journal 5 years ago [1]. The present and that paper (titled *How to attain sustainability in energy supply?*) do cover the unique field of Raw Materials. In order to unify them, the energy is to be regarded as raw material, maybe the most important one.

Such speculation provides me a justification to use the introductory part of paper [1] for the same purpose in this paper too. So, I am repeating it in condensed form:

A survey is given of global energy supply today and the possibilities for supply in future. As a basis, the following facts are used:

1. Human population on our planet registers a permanent increase,
2. The total quantity of raw materials spent worldwide increases by an accelerated rate and
3. The *per capita* consumption of raw materials grows as well. This trend is opposite to the quantity of raw materials resources, which decreases with time. The intensified expansion of spending habits, as well as the jump in increase of raw materials specific consumption in former poor countries that now reach the level of economic expansion is the main reason for such a phenomenon.

The conclusion that results is simple and obvious: the Mankind does exhaust the resources. The renewable ones disappear faster than the nature could replenish them, while the non-renewable resources are approaching the level of critical reserves [2, 3].

This serious depletion of raw materials was caused with the irrational consumption in a number of past decades. Simply, we did practice a lifestyle of unlimited wants in a world of limited resources.

2. TIMELINE OF MANKIND'S PATHWAY TO DEPLETED RESOURCES

If we analyze the consumption patterns in the last 150-170 years, we will recognize the following characteristic periods.

1. Before the ~1870s, i.e. before the Industrial Revolution, the prevailing concern of humans was how to survive in a world of limited and

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Paper received: 27. 03. 2018.
Paper accepted: 12. 04. 2018.
Paper is available on the website: www.idk.org.rs/journal

unstable food provision, elementary health protection and frequent spreading of diseases with lethal end. The safety issue was as well one of the major concern. In these periods the raw materials, seen with the today's diopter, were practically untouched, i.e. the global population was about 1.2 billion people [4, 5], and the consumption habit was modest or less, so that for the nature it was no problem to replenish the spent resources.

2. The period some hundred years after the Industrial Evolution experienced continuous improvement of the life quality. The production of goods did increase and diversify, and that was done with less human efforts. The materials started to be utilized on an accelerated manner, because the nature's reserves were practically untouched. That was the beginning of the modern style of life [6].
3. Next was the period from the 1970s until now. The spending habits did grow and grow; the luxury and the careless consumption of goods of every kind did reach an unacceptable level. Normally, some resources entered in their final phase before exhaustion [6].
4. The last period is - our immediate future[1]. To be objective, let take in consideration all possible future developments.

The worst scenario will be if we experience shortage of vital raw materials, or even their near complete exhaustion. It will not be easy to adjust our lifestyles to such a new reality: how to manage the life without something that was always at our disposal and we did expect that it will be so forever. It will be terrible to survive and to cope with such a cruelty.

Next is the case of moderate decline in raw materials supply. It will be accepted with relief compared to the worst scenario, but in any case it will mean less comfort and spending freedom than with the standard of previous periods.

The most desirable is the scenario of further increase in raw materials supply, both in quantities and in diversification. Prolongation of the careless wellbeing based on plenty of goods that the consumers could afford without significant efforts. It is hard to believe that such an option will occur unless some 'miracle' does not happen: Some unexpected and maybe unearned gift that belongs to the class of serendipities[2]. That may be some longtime dreamed achievement or breakthrough.

[1] Niels Bore (1885-1962) used to say: Prediction is very difficult - especially about the future!

[2] *Serendipity* = finding things without searching for them (term coined in 1754 by H. Walpole; One of the ten English words hardest to translate)

On the basis on facts listed above we could formulate the following:

1. The quality of contemporary life is interconnected with the quantity of consumed materials [6].

2. Normally, the quantity of materials is in a tight relation with the quantity of available raw materials. The latter category is endangered, thus indicating that humans could not afford any more such unlimited appetite for goods. The mankind is faced with the puzzle*: how to balance the increased per capita consumption multiplied by the increased global population, with the stubbornly depleting quantity of raw materials?*

Here is an example that illustrates the problem: copper ores extraction threshold in the year 1900 was more than 3% Cu in the ore [6]. In the 2010s it falls down to 0.06% Cu [7]. This means that for winning the same quantity of copper it was necessary to mine, dress and treat 50 times more ore. In the same time this means that one should spend some 50 times more energy for the listed operations.

Contemporary metallurgy somehow managed to extract copper under these unfavorable conditions. But the extraction threshold will decline further to lower and lower copper content. So what will we do when it will reach the value of 0.01% Cu, or further – the terrible 0.001% Cu.? No need to explain the meaning of these figures. Instead, we should admit and be obliged to propagate a serious alarm.

There is some relief in the fact that not all alarming cases did later confirm their validity. In some cases exploitation of given raw material continues far longer than the alarm estimated, but such examples are rather exception than rule[3].

3. SEARCH FOR NEW RAW MATERIALS SOURCES

There is anymore no place for doubts that raw materials are not critically depleting, nor place for expectation that in finding solution fortune will work instead of us. Search for dependable and stable worldwide ores supply is of primary importance!

The proper search for raw materials supply in future is to be comprehensive, without avoiding any possibility, no matter how non-realistic it may seem

[3] In 1995s the estimate of remained resources was [8]: Fe ~ 200 years supply; Zn ~ 40 years, Pb ~ 30 years and Sn ~ 15 years. The deadline for tin reserves exhaustion did expire, but this metal continues to be mined and wined. The exactness of analytical methods, as well as discovery of new sources and/or some error in calculation are possible reasons for such confusion

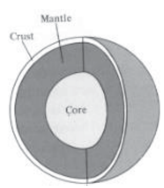
at first sight. The existing methods will be enriched by new, including some extraordinary ones. No limitations should be applied, at least in the screening stage. This means that, e.g. sources situated far below or far above the present ones are to be taken in consideration too.

4. THE EARTH HAS A MANTLE AND A CORE TOO!

The closest example of such approach is to try to exploit raw materials from Earth's interior, i.e. mantle and core. In Table 1 a reminder is given with basic data for the structure, composition and size of the Earth's interior [9]. Enormous quantities of valuable raw materials are stocked there in relatively pure state, but at temperatures (up to 6.000 ºC) that are far out of the recent span of operational conditions. Further, the distance below ground level reaches more than 6.000 km. Both parameters make unreasonable the very idea of so deep underground mining (in the 21st Century, or so). But, for the centuries to come the possibility stays open.

Table 1. Basic parameters that characterize Earth's interior [9]

Tabela 1. Osnovni parametri unutrašnjosti planete Zemlje [9]



Earth part	Depth, km	Temperature	Me content
Crust	40	< 40 ºC	~70 metals
Mantle	2900	2.000 – 3.000 ºC	Mg, Fe, Ca, Al, …
Core	3500	3.800 – 6.000 ºC	Fe, Ni, …

Titan from Mars?

Since the beginning of the Space traveling era, half a Century ago, a lot of data that characterize the planets were accumulated. Due to such activities today we know more and more about the planet's distances, trajectories, chemical composition, etc. So, as early as 1976' Viking mission, we did learn that the Mars soil contains Ti (0.9%) [10]. This data was further verified in 2012 with the first laser spectrum taken on Mars (Fig. 1). Other metals, like Fe, Mg, Al, Ca, etc. were detected as well [11].

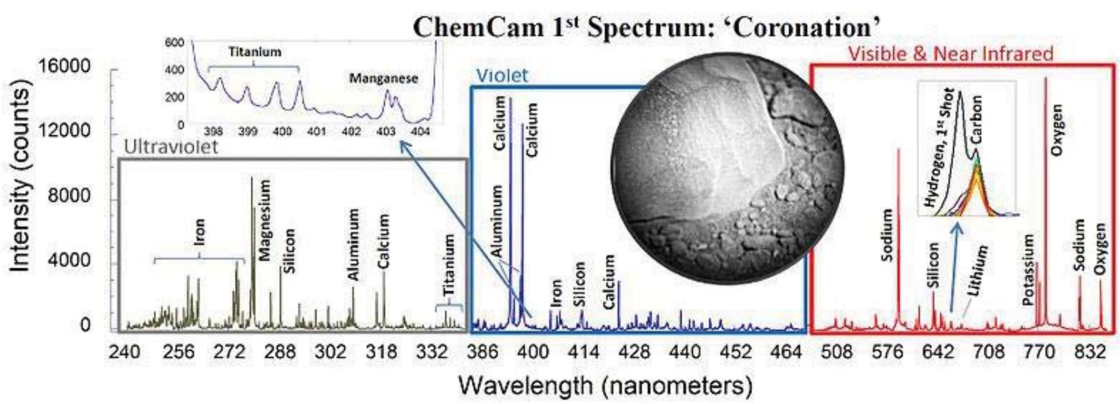


Figure 1. First Laser Spectrum from Mars, Curiosity Rover, 'Coronation' Rock, 2012 [11]

Slika 1. Prvi laserski spektar sa Marsa, 2012 [11]

So this will possibly raise hope that raw materials may be harvested from space bodies.

Closer studies of the conditions there are not so optimistic. According to the data presented in Table 2, the atmosphere on Mars contains almost 95% of CO_2 and only 0.13% O_2 [12]. The most relevant burden is the distance from Earth. It varies between 55 and 100 million kilometers and is the determining factor that prevents Mars to be a source of raw materials in near future.

Table 2. Composition of the Mars' atmosphere [12]

Tabela 2. Sastav atmosphere Marsa [12]

Component t	CO_2	N_2	Ar	O_2	CO
%, vol.	95.3	2.7	1.6	0.13	0.08

Frankly, for the time being, the substitution of traditional resources with some new (and extravagant) is not realistic. Digging minerals in the extreme depth of our planet or bringing them from planets at a distance of hundred million kilometers should wait until our technical expertise reaches new frontiers. Instead, it is better to try again and more carefully with our traditional sources of raw materials, but with improved technologies in treating them and with new patterns in consuming them.

As far as the new technologies are concerned, we do witness a continuous development that results in more sophisticated products, new properties of materials, better performances, achieving new frontiers and satisfying unpredictable requests. In doing so, a number of problems arise and need to be solved. One of them is, e.g., how to recognize what will be the needs of tomorrow, but to do that with the knowledge of today?

Consumption patterns are as well an important issue in solving the problem of satisfying materials supply of tomorrow. Warning comes with the experience that over the 20th Century consumption of goods (metals, glass, wood, cement, chemicals, etc.) jumped for 15-20 times [13], no matter that the global population for that period rose only 4-5 times. The difference until 15-20 times is caused by the increase of per capita consumption. This is why smarter consumption must be taken in consideration when dealing with this field. Recycling, miniaturization, (nano-sized products!) etc. are just few possibilities how to rationalize consumption patterns.

5. DOUBTS

When dealing with the indicators as above, a number of doubts arise and impose double checking, and similar precaution measures to be applied.

One of the doubts is already mentioned discrepancy between the estimated and the proven data of the praxis, as illustrated with the example with tin's primary sources reserves. One should keep in mind that, next to the listed arguments, i.e. new discoveries, improved detection methods, recycling, and new developments, one should always bear in mind an extra one, and this is eventual *speculation*, due to economic, political, or other reasons.

The possibility to produce new materials from the 'old' raw materials generates other doubt.

In 1985 the scientific community was surprised with the discovery of fullerenes, the third variety of the element carbon. From the ancient time it was believed that carbon could exist only as graphite and diamond (if we disregard the soot). Soon after the 1985-news, another two carbon modifications were discovered: carbon nanotubes and graphenes. Their miniature size and excellent mechanical, thermal, electronic, etc. properties opened a new era of sophisticated materials, with a number of applications. So, the possibility to produce 'new' materials or products from old raw materials raises hope that this could be repeated with other traditional raw materials and enriches the menu of useful materials. Silicon is candidate for such a role. His abundance recommends him as practically non-exhaustive raw material (sand), while the properties of ultrapure Si make him the 'heart' of computer chips. Why not expect more sophisticated but cheaper Si-based goods in future?

So the problem of depleted raw materials could be by-passed by engineering of other C- or Si-based materials. Any other abundant raw material that in the past was disregarded as useless could eventually become valuable resource.

The odds of increasing-availability and decreasing-consumption of raw materials

Let's turn back and concentrate on solving the puzzle of balancing the present <u>quantity of raw materials</u> (RM) with their demand, i.e. the product of <u>world population</u> (WP) and <u>per capita consumption</u> (PCC). In order to achieve the balance, either the quantity of RM should be increased or the latter two parameters should be adequately decreased. In doing these increase/decrease operations one should take into consideration the following:

In present circumstances, it is troublesome to impossible to increase the **quantity of raw materials**.

The most promising solution is wining new raw materials from already existing, but so far not exploited (disregarded) resources.

Next possibility for getting new raw materials is the one based on new developments in technology. Since the famous historical example with Thomas Malthus' catastrophic warning in 1800s, the mankind did realize (and accepted!) that <u>technology creates resources</u> [14].

Reduction of population on a global level is a doubtful possibility. Substantial reduction could be achieved on many ways, but all of them suffer of some drawbacks.

They could be either (a) <u>*enforced*</u> (French: *force majeure*), as e.g. global disasters (diseases, starvation, tectonic or other natural catastrophes), climate changes, etc., or (b) <u>*obligatory*</u>*,* as e.g. the strict birth control similar to the one applied in Mao's China (one child per couple!), or (c) <u>*unpopula*r</u>, as wars etc., or (d) <u>*far from realization*</u>, (as e.g. colonization of other planets, because this needs further and substantial advance in technology etc.).

Per capita consumption rationalization could be realized only driven by strong motivation of philosophical, religious, physiological, life style or other nature. Any of these rationalizations is desirable, but low probable. The 'natural' course of consumption patterns is towards the opposite direction. More precious qualities, as e.g. conscience, humanity, etc., are needed to drive this change in a desirable direction.

6. CONCLUSION (TENTATIVE)

The analysis up to now shows that the expectations from extraordinary sources of raw materials were in vain. Further advance of science, research and development, etc. are the real means that could provide raw materials for the centuries to come. Some doses of optimism is welcomed to accompany them.

In other words, raw materials crisis does exist, but isn't without feasible solutions.

This 'philosophical' conclusion does not tell anything concrete, and may be also understood as: we don't know how to provide materials for tomorrow!

New opportunity: Space mining

Quite unexpectedlie for a scientist self-imprisoned within the terrestrial frame as exclusive raw material source, a novelty named Space Mining did appear. This speculative title was probably so coined in order to attract a wider attention and - support. And it really did, at least with this author.

In few words the story went/goes like this: A small asteroid, made almost of pure iron, was discovered [15]. It was announced as 'possessing unlimited reserves of iron', more precisely 'the quantity 100 times more valuable than US Economy'. In case of successful exploitation it was declared as able to turn up-side-down the existing order in materials supply on Earth, i.e. – to ruin global economy!

It was discovered long ago (in 1852), and named ***16 Psyche*** [16]. Positioned between Mars and Jupiter [17], at a distance that it will take five years for the first expedition to arrive there (in 2026, as estimated) [16]. It is one of ten most-massive asteroids, but also the most-massive *metallic* asteroid, with ~10^{19} kg, (i.e. the ore supply for 'several millions of years' (!?)).

His eventual exploitation will start a new era – Era of Space Mining!

Asteroids and minor planets are possible target of the activity aimed to take advantage of their minerals and volatiles. Different exploitation possibilities are under consideration, as e.g. [18]:

1. Bring asteroidal material to Earth,
2. Process it on site and bring only processed material and
3. Transport asteroid to orbit around Moon, Earth or Interplanetary Space Station.

No matter where in space, the extraction will be performed by some of the following technics:

(a) surface mining,

(b) shaft mining,

(c) magnetic rakes or

(d) heating (to extract water or volatiles).

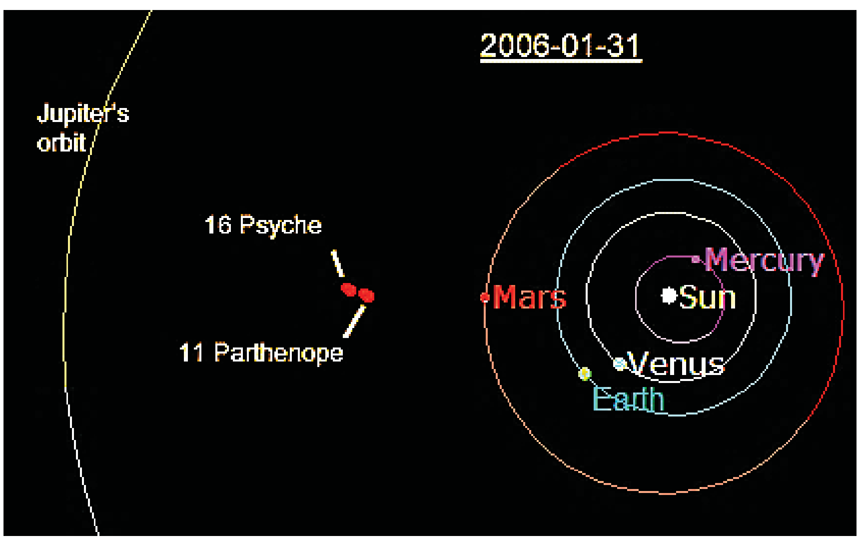


Figure 2. Schematic of 16 Psyche position in the Solar system [17]

Slika 2. Shematski prikaz položaja asteroid 16 Psyche u Sunčanom sistemu [17]

Recent (and future) problems

In contrast to terrestrial mining, the only recent source of raw materials, the parameters of space mining are burdened with many uncertainties. The only known fact is that high costs, and a number of unknowns will accompany such a mining. Ore quality, costs, mass of extraction equipment etc. are among the items to be closer defined in future.

Different problems are envisioned and discussed as, e.g.:

- What if the transportation expenses exceed the market value of the mined materials,
- Price issue: deficit or/and precious metals are worth of bringing, while abundant metals (e.g. Ni) are not economically viable.
- It is possible the transported metal to experience price dumping due to its increased availability from space.

Within time, cost leveling may occur as result of increased terrestrial *costs* (due to further resources exhaustion, increased raw materials consumption, etc.) vs. lowering the *costs of space mining*. In such a case the space mining from present days' label 'impossible', may switch to 'maybe possible'.

No matter how illusion-full, the described alternative for raw materials supply deserves our attention because it opens a new possibility to solve an existential trouble. Once started, it is expected that the success in realization will increase step by step and eventually will solve (or at least support) the solution.

So, let's say welcome to the Space Mining novelty!

No matter when it will be effective.

One day it will be – for sure!!

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IZVOD

SIROVINE ZA BUDUĆNOST: IMA LI NOVIH IZVORA?

Dat je pregled sadašnjeg stanja rezervi sirovina, trendova njihove potrošnje i slično. Potvrđen je fakt da se sirovine i dalje iscrpljuju i da je moguća kriza u snabdevanju sirovinama u budućnosti. Identifikovane su komponente kompleksa zalihe/potrošnja i dalje analizirane u pokušaju da se približimo njihovom balansiranju.

Prihvaćen je pristup da se ne ograničava izbor mogućih izvora sirovina, tako da su razmatrani i neki neuobičajeni izvori. Na primer, analizirane su mogućnosti eksploatacije metala iz velikih dubina unutrašnjosti Zemlje, kao i sa drugih planeta (Mars). Bez obzira na to što je izvodljivost ovih postupaka u bližoj budućnosti malo verovatna, treba ih ipak imati na umu kao mogućnosti koje mogu da ponude nove tehnologije.

Odabrana je i analizirana i jedna druga, potpuno futuristička mogućnost. Snabdevanje rudama iz svemira, predmet snova iz nekadašnjih vremena, izgleda da se bliži svom ostvarenju. Pažnju nam privlači asteroid sa izuzetno visokim sadržajem gvožđa. Nazvan ***16 Psyche****, metalni asteroid sa najvećom masom, najavljen je da može omogućiti snabdevanje gvožđem za "nakoliko miliona godina" (!?). Bez obzira na njegovu veliku udaljenost od Zemlje (predviđa se da će ekspediciji do njega trebati čitavih 5 godina svemirskog putovanja), u toku su analize i druge konkretnije aktivnosti koje treba da nas pripreme za prihvatanje ovako izvanrednog 'poklona sa neba'. Već se uveliko razmatraju načini moguće eksploatacije, parametri rudarenja u vasioni, troškovi, pravo sopstvenosti i drugi ekonomski aspekti. Najizraženija (i najcenjenija) osobina ovog asteroida je što on nema koru, odnosno ima samo metalno jezgro, tako da ne postoji sloj nemetalne raskrivke koji se mora ukloniti da bi se došlo do metala.*

Ključne reči*: sirovine, izvori, tradicionalni i novi (revolucionarno novi), snabdevanje rudama iz svemira.*

Pregledni rad
Rad primljen: 27. 03. 2018.
Rad prihvacen: 12. 04. 2018.
Rad je dostupan na sajtu: www.idk.org.rs/casopis