MSP-REFRAM

Coordination and Support Action (CSA)

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Second Workshop (preparing the future)

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Multi-Stakeholder Platform for a Secure Supply of Refractory Metals in Europe

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Summary

Second Workshop (preparing the future)

Approval

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CONTENT

INTRODUCTION

The second workshop (WS2) within the MSP REFRAM-project was held in Brussels, Thon Hotel Brussels City Centre, on 27-29 of September 2016 with the objective to bring forth potential innovative pathways identified in order to optimize the balance between resource availability and usage of the selected refractory metals. In particular, the WS2 was intended to shed light on the following areas:

1. Current usage of selected refractory metals in the key value chains of the EU. Future applications and forecast for the EU (WP1)
2. Innovation potential in the recovery of refractory metals from primary resources (WP2)
3. Innovation potential (barriers and opportunities) in the pre-treatment of waste streams considered as secondary source of refractory metals (WP3)
4. Innovation potential (barriers and opportunities) in the recovery of refractory metals from urban mines (WP4)
5. Potential to substitute the selected refractory metals in the most relevant applications in the EU (WP5)

METHOD

The workshop was structured by WP sessions; WP leaders were responsible for the organization and control of each WP session and its outcomes.

Relevant experts were selected and invited to the WS2 and were asked to make specific presentations by the end of each WP bringing their view and adding to what was being presented.

Summary sessions were scheduled where WP leaders presented the key findings and conclusions of each WP after discussions and contributions from partners and experts during the workshop.

AGENDA

Tuesday 27 September

12h00 – 14h00: Lunch

14h00 – 15h00: Work package 1

1. Coordination of the Multi-stakeholder platform and External Expert Committees
   Susanna Casanovas, Amphos 21
2. Current and future needs of the EU industry in refractory metals (Ta example)
   Didier Hartmann, CEA
3. Current state of value chains of Nb in the EU (D12)
   Jean Marie Lambert, ERAMET
4. Current state of value chains of Re in the EU (D12)
   Susanna Casanovas, Amphos 21
5. Current state of value chains of W in the EU (D12)
   Jason Yang, GTK
6. Current state of value chains of Mo in the EU (D12)
   Xianfeng Hu, MEFOS
7. Task 1.3: MATCH BETWEEN SUPPLY AND DEMAND OF THE 5 REFRACTORY METALS IN THE EU

Gaetan Lefevre, BRGM

15h00 – 15h45: Experts' feedback and discussion

- Eco-efficiency indicator framework implemented in the metallurgical industry. Various case studies, exergy, simulation etc.
  Markus Reuter, Helmholtz Institute for Resource Technology

15h45 – 16h15: Coffee break

16h15 – 17h15: Work package 2

1. Title: **Mining and Mineral Processing_Primary Resources**
   Speaker: Jason Yang, GTK
   Contributors: Kathy Bru, BRGM (W); Jason Yang, GTK (W, Mo)
2. Title: **Tantalum /Niobium Processing**
   Speaker: Florent Bourgeois, LGC
   Contributors: Florent Bourgeois, LGC (Ta, Nb); Witold Kurylak, IMN (Nb, Ta, Re)
3. Title: **Innovative Technologies for Hydrometallurgical Extraction of Refractory Metals from Primary Resources**
   Speaker: Sami Virolainen, LUT
   Contributors: Eugen Andreiadis and Daniel Meyer, CEA (Ta, Nb);
   Stefan Willersinn, UNIKL (W); Tuomo Sainio, Sami Virolainen and Markku Laatikainen, LUT (Mo)
4. Title: **Innovation Potential in Recovery of Refractory Metals from Primary Resources: Pyro-metallurgy**
   Speaker: Xianfeng Hu, MEFOS
   Contributors: Xianfeng Hu, Lena Sundqvist Ökvist and Guozhu Ye, MEFOS (W, Mo); Yongxiang Yang, TUDELFT (Mo); Bertrand Dusanter, ERAMET (Ta, Nb)

17h15 – 18h00: Experts' feedback and discussion

- Challenges of the environmental rehabilitation of abandoned mining areas in Portugal.
  Alexandra Ribeiro, CENSE
- Environmental assessment of innovative technology
  Lukasz Lelek, Mineral and Energy Economy Research Institute of The Polish Academy of Sciences

19h30: Dinner at restaurant Brasserie Leopold

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Wednesday 28 September

9h00 – 10h00: Work package 3

1. Title: Mining and Re-processing of Tailings
   Speaker: Jason Yang (GTK)
   Contributor: Jason Yang (GTK).
2. Title: Innovation potential in the recovery of Mo
   Speaker: Xianfeng Hu (MEFOS);
   Contributors: Xianfeng Hu, Lena Sundqvist Ökvist and Guozhu Ye (Swerea MEFOS); Sami Virolainen, Tuomo Sainio and Markku Laatikainen (LUT).
3. Title: Innovation potential in the recovery of W
   Speaker: Stefan Willersinn (UNIKL);
   Contributors: Stefan Willersinn & Hans-Jörg Bart (UNIKL).
4. Title: Innovation potential in the recovery of Nb and Ta;
   Speaker: Eugen ANDREIADIS (CEA);

Contributors: Eugen ANDREIADIS (CEA); Marta Macias Aragonés (IDENER).

5. Title: Innovation potential in the recovery of Re
   Speaker: Sami Virolainen (LUT).
   Contributors: Sami Virolainen, Markku Laatikainen and Tuomo Sainio (LUT); Witold Kurylak (IMN); Marta Macias Aragonés (IDENER); Eugen Andreiadis (CEA).
6. Concluding summary of WP3
   Speaker: Lena Sundqvist Ökvist (Swerea MEFOS).

10h00 – 10h45: Experts' feedback and discussion

- Some Current Australian R&D Focused on Mo Recovery and related Sustainable Mine Operating Opportunities.
  Chris Ward, AMIRA International
- Boliden Kokkola. Forerunner in responsible metals production
  Justin Salminen, Boliden Kokkola

10h45 – 11h15: Coffee break

11h15 – 12h15: Work package 4

1. Recycling of End-of-Life Products, Speaker Andrzej Chmielarz (IMN);
2. Innovation potential in the recovery of Mo, Speaker Xianfeng Hu (MEFOS);
3. Innovation potential in the recovery of W, Speaker Jason Yang (GTK);
4. Innovation potential in the recovery of Nb, Speaker Yongxiang Yang (TUDelft);
5. Innovation potential in the recovery of Re, Speaker Sami Virolainen (LUT).
6. Innovation potential in the recovery of Ta, Speaker Nourredine Menad (BRGM)

12h15 – 13h00: Experts' feedback and discussion

- Economic and environmental impact estimations from innovative technologies to be applied to Mo/Re/Ta/W/Nb from secondary sources;
  Liesbeth Horckmans, VITO NV
- Energy-Environmental impact assessment of technologies.The issue of rarity.
  Antonio Valero, CIRCE.

13h00 – 14h30: Lunch

14h30 – 15h30: Work package 5

1. WP5-Substitution potential of refractory metals: Niobium
   Ashok Menon and S. Erik Offerman, TU Delft (presented by Marjaana Karhu, VTT)
2. WP5-Substitution potential of refractory metals: Tantalum
   Marjaana Karhu and Päivi Kivikytö-Reponen, VTT
3. WP5-Substitution potential of refractory metals: Rhenium
   Katarzyna Bilewska, IMN, (presented by Marjaana Karhu, VTT)
4. WP5-Substitution potential of refractory metals: Molybdenum
   Katarzyna Bilewska, IMN, (presented by Marjaana Karhu, VTT)
5. Tungsten industrial scenarios, concepts and substitution potential
   Dr. Santiago Cuesta-López and Dra. Rocio Barros, ICCRAM

15h30 – 16h15: Experts' feedback and discussion

16h15 – 16h45: Coffee break

16h45 – 17h00 Work package 7

- Interregional mirroring strategy, application to raw materials and mining, Santiago Cuesta (ICCRAM)

..17h00 - 18h00: Discussion and preparation of the WP summaries
19h30: Dinner at restaurant Belga Queen

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Thursday 29 September
9h00 – 9h45: Summary of Work package 1
9h45 – 10h30: Summary of Work package 2
10h30 – 10h45: Coffee break
10h45 – 11h30: Summary of Work package 3
11h30 – 12h15: Summary of Work package 4
12h15 – 13h00: Summary of Work package 5
13h00 – 14h00: Lunch

SUMMARY WP1 – MULTI-STAKEHOLDERS PLATFORM

INTRODUCTION AND EXPECTED OUTCOME

In the framework of WS2, WP1 was expected to provide information about:

- *Current and future needs of the selected refractory metals in the EU*,
- *Present EU industrial value chains of the selected refractory metals,*
- *Balance between EU reserves and demand: supply chain of the selected refractory metals*.

KEY FINDINGS

During the presentations and discussions of WP1, the common limitation for the achievement of the expected outcomes is the lack of reliable figures on EU value chains of the selected refractory metals. In addition to the lack of certain data, harmonization is needed among available figures, e.g. year, geographical scope, categories/flow definitions (e.g. waste), metal content, etc. In this context, particular limitations to the extraction of imports and exports through Eurostat (ComExt) are identified:

- Metals such as rhenium, tantalum and niobium in residues are reported along with other elements so the flow of each metal alone cannot be reliably estimated.
- Custom codes refer to material trade but are never related to metal content, the estimation of which is impossible to determine for setting up mass balances.
- The equation **import-export=needs** does not directly represent EU consumption as stocking is not taken into consideration.
- Different definitions of recycling rates (from EoL products or from metal recycled content may lead to misunderstanding of figures.

The mass balance of EU value chains (production, import/export of products/articles, recycling, import/export of wastes, etc.) are mainly determined by economic factors. The refractory metal market is generally small, global and very dynamic, which hinders the identification of defined patterns. In this context, companies usually keep their production/consumption data as confidential, making it highly difficult to collect reliable figures of EU consumption. Similar to present consumption, the forecasts on future consumption were even poorer, particularly for the EU.

The need for inputs from external experts (industrials) or consultants (Roskill) was several times discussed as a potential solution to the gaps/uncertainties on EU value chains. Regarding Roskill, a new release with data on metals world demand was mentioned; however, it was questioned whether it contained EU relevant data for the project. Thus, a meeting with Roskill representatives was suggested in order to elucidate whether its services could be valuable for the project and to negotiate a reasonable price for their services if appropriate.

The direct involvement of related industrial plants was also discussed but it was stated that some of the companies were reluctant to participate in MSP REFRAM project to avoid providing strategic information on their activities.

In this sense, it was finally agreed that the obtaining of reasonable estimated figures, with a good traceability on assumptions, would be sufficient in view of the objectives of MSP REFRAM project.

CONCLUSIONS

After the presentations and discussions within WP1 session, it was concluded that information is scarce when identifying current and future needs and value chains of selected metals in the EU.

The mass balance of EU value chains are mainly determined by economic factors in a global, small and dynamic market. In this context, companies usually keep their production/consumption data as confidential, making it highly difficult to collect reliable figures on EU consumption or future forecasts. External inputs, e.g. Roskill will be further considered in order to address data gaps and/or uncertainties.

The obtaining of reasonable estimated figures, with a good traceability on assumptions, will be sufficient in view of the objectives of MSP REFRAM project.

FUTURE WORK

From what was found and discussed within the WP1, the following steps are to be covered:

1. Filling the gaps in the assessment of EU current and future needs and harmonizing value chains of the selected refractory metals (D111 Report on current and future needs of selected refractory metals in the EU).
2. Analysis of balance between EU reserves and EU demand: supply chain (D131 Report on balance between demand of supply of refractory metals in the EU).
3. Evaluation of the feasibility of key innovation technologies for the recovery from primary and secondary resources in the EU - WP2, WP3, WP4 and WP5 outputs.
4. Design of future EU industrial value chains in order to balance metals supply vs. demand.
5. To identify the potential barriers/limitations due to regulations, standards, politics etc. (D141 Report on potential innovation pathways to balance demand and supply of refractory metals in the EU).

SUMMARY WP2 – PRIMARY RESOURCES

INTRODUCTION AND EXPECTED OUTCOME

In the WS1 the technologies of mining, mineral processing and extractive metallurgy (hydro-metallurgy and pyro-metallurgy) are reviewed on recovery of refractory metals from primary resources. In the WS2 the innovative investigations of these technologies on tungsten, molybdenum, tantalum and niobium are presented. The technological innovations of rhenium are covered in the WP3 for secondary resources because rhenium is produced as by-product in molybdenum and copper processing.

The technological innovations collected through literature review (published articles, industrial reports, patents, and partners' research work etc.) include ideas, laboratory and pilot scale investigations and test work, and operational practices. These innovations are mainly concentrated on:

1) Improvement of process safety such as in ore mining processes rockburst and roadways stability being investigated,
2) Concerning environmental impact such as new roasting processes being developed to reduce the emission of sulphurous gas and dusts,
3) Saving energy and decreasing process cost and chemical consumption, e.g. new direct alloying steel with tungsten by tungsten ore in pyro-metallurgy and improved acidic leaching and biosorption process in hydrometallurgy for tungsten extraction,
4) Increasing process efficiency, metal recovery and product quality (grade, purity), e.g. combined gravity-magnetic-flotation process for complex tungsten ores processing, and novel molybdenum leaching methods of alkaline pressure leaching, oxidant additives leaching and bioleaching etc., and
5) Solving special problems on technology, e.g. fine and ultrafine minerals processing by carrier flotation, high gradient/intensity magnetic separation and centrifugal concentration techniques, and oxychlorination for low-grade molybdenum concentrate etc.

KEY FINDINGS

MINING TECHNOLOGY

Studies and operational practices mainly in tungsten and molybdenum mines on rock slope engineering , rockburst, roadways stabilities, intelligent mining, mining techniques, filling technology were discussed. Because mining is a very risky business, innovations are considered much slower than other industries. The investigations mainly focus on the improvement of mining efficiency and the safety of mining as well.

Due to the limitation of published articles in English the detailed data and information have not presented in the deliverable which would be added in the future work.

MINERAL PROCESSING

TUNGSTEN

The innovative studies on selective reagent development, combined gravity-magnetic-flotation process, improving Petrov's process for scheelite concentration and fine mineral flotation techniques were presented. According to the experts' comments, detailed data and information need to be added. And some studies on pre-concentration such as sorting technology and comminution (crushing, grinding) may need to be collected. The difficulties could be that most published articles are in Chinese and hard to be downloaded.

MOLYBDENUM

The operational innovations of flotation process and studies on flotation reagent development were presented. The same as on tungsten, more detailed information about techniques should be provided such as flowsheet, conditions (reagents, temperature, material properties etc.), and scale (lab, pilot, industrial) etc.

TANTALUM AND NIOBIUM

Industrial beneficiation techniques of tantalum and niobium bearing ores were presented including crushing, grinding, conventional gravity concentration (jig, shaking table), and centrifugal (spiral) and enhanced gravity separation (MGS, Falcon concentrator), depending on the size of the liberated particles, and selective reverse flotation to concentrate the finest material. No many published articles about tantalum and niobium mineral processing have been found. Some published papers on the IMPC 2016 in Québec Canada were listed. Finally, the knowledge and technical innovations on the beneficiation of fine and ultrafine Ta-Nb bearing ores were briefly discussed.

HYDROMETALLURGY

TUNGSTEN

Innovative studies on acidic leaching with nitric and phosphoric acid, biosorption (applied for alloy scrap), direct solvent extraction from alkaline medium and emulsion liquid membranes, including flowsheet, conditions and results, were presented. The economic and environmental benefits of the techniques were discussed and the future challenges on the hydrometallurgical extraction of tungsten such as decreasing tungsten losses in conventional precipitation purification and decreasing chemical consumption and improving the efficiency of conventional ion exchange and solvent extraction methods were described.

MOLYBDENUM

Conventional processing flowsheet and innovation potential were presented which include novel leaching methods and novel separation and purification methods. Different novel leaching methods including alkaline pressure leaching, oxidant additives leaching and bioleaching were compared to the conventional acidic pressure leaching technically on the aspects of yield, purity, reagent consumption and temperature, etc. Innovative studies on precipitation, solvent extraction, and ion exchange including process, conditions, results and mechanism were also described. The innovation potentials of these methods were discussed.

NIOBIUM AND TANTALUM

Conventional leaching method using HF is hazardous for people and environment due ti volatilization of HF. Two alternative methods by using NH4F2 and KOH/NaOH were indicated and compared to the conventional one. For solvent extraction the processes with different extractants were presented and compared on selectivity, flowsheet and potential for use etc.

PYRO-METALLURGY

TUNGSTEN

Three innovative processes were presented and discussed.

1. Direct alloying steel with tungsten by tungsten ore

In the process, the mixed tungsten ore and carbonaceous material are charged into the melting furnace and the steel is directly alloyed with tungsten. This process has the advantages of one-step process, being economical and energy efficient. It is also possible to alloy steel simultaneously with molybdenum and tungsten by charging technical grade MoO3 and tungsten ore into the furnace. The pilot trials were carried out and the proposed process was reported to be industrialized in some mills in China.

2. WC production by one-step carbonization

The direct carbonization by mechanical alloying was presented in which mix of tungsten oxide and carbon powder, mechanically processed in a mill and formation of WC with the help of generated energy during milling are included.

3. Electrolytic process for the preparation of tungsten powder and tungsten carbide

In this process, the metal oxide is made into cathode and soaked in the molten salt. Under the driving force of the direct current, oxygen in the metal oxide is ionized and transported to the anode through the molten salt. The net result is the production of metal at the cathode and evolution of CO/CO2 at a graphite anode or O2 at an inert anode. Compared to the traditional reduction process, the electrolytic process exhibits a high yield and high energy efficiency. But the problems are formation of tungsten-containing volatile materials and dissolution of $CaWO_4$ in the molten salt.

MOLYBDENUM

The following innovative processes were presented and discussed including flowsheet, technical conditions and results. The advantages and problems compared to traditional methods were briefly analysed for some of these processes.

The processes of the liquation smelting Cu-Mo concentrates and the oxychlorination for processing low-grade molybdenum concentrates; the low temperature oxidizing-chlorinating roasting, the direct reduction by manganese, the co-roasting molybdenum concentrate and pyrolusite (MnO_2), the plasma smelting for direct FeMo production and the direct reduction of MoS_2 are potential alternative oxidative roasting methods; and the refraining of the volatilization of MoO_3 is a potential for adding MoO_3 to the steel method.

NIOBIUM AND TANTALUM

The innovative techniques were presented from two aspects 1) alloying steel by niobium-containing oxide including the processes of direct alloying steel with niobium by niobium-rich slag and direct use of Nb_2O_5 for special alloy production, 2) reducing niobium/tantalum oxides including the process of producing niobium/tantalum metal powder by reducing their oxides with magnesium vapour. The flowsheets, technical conditions, results and advantages of these processes were described.

CONCLUSIONS

Generally, the new innovative processes for recovery of tungsten, molybdenum, tantalum and niobium from primary resources in mining, mineral processing, hydro and pyro metallurgy have been collected in our deliverable in which some were studies and tested in laboratory or pilot scale and some were tested or applied in industrial plants. This information contains technical flowsheets, conditions and results, and discussions on economic cost, energy efficiency and environmental impact by comparing the innovative techniques to the traditional ones which provide potentials to be applied industrially in the future in EU. But as some experts had commented during the workshop the data and information of some processes are missed or not detailed such as flowsheet, conditions, results and material properties etc. Meanwhile, more discussions about the feasibility of innovative techniques should be added which may involve in technology development, economy estimation, environmental impact and regulators of the mining industry and any issues of society such as through education to strengthen innovation on primary mining industry.

Some difficulties have been found during our data collection and study work. For example, the published articles about Ta-Nb mineral processing are limited. Some publications are in other languages and difficulty to find complete papers or data.

FUTURE WORK

1) **Mining technology:** More details about the innovative techniques especially the mining of tungsten will be added.

2) **Mineral processing:**
    a. For tungsten and molybdenum, more details about the innovative techniques are added such as flowsheet, conditions, results and properties of head materials. Some missed techniques e.g. sorting techniques for pre-concentration of tungsten ores, techniques on ore comminution (more efficient crushing and grinding techniques etc.) may also need to be added.
    b. For tantalum and niobium, more information about Ta-Nb mineral processing should be collected.

3) Hydro-metallurgy:
    a. For tungsten a challenge is to increase the leaching yield and/or to reduce the tungsten content in residues or tailings, therefore innovative concepts are reviewed. The Innovative technologies are evaluated for their environmental and economic impact. A cost and benefit analysis is conducted in order to determine the competitiveness and to further increase recycling rates.

4) Pyro-metallurgy:
    a. For tungsten and molybdenum the advantages and disadvantages of the proposed innovative technologies will be tabled and be compared with those of the existing technologies. Raw materials involved in the innovative technologies will be considered and selected technologies will be evaluated in the aspect of technological and economic feasibility for industrial application within EU.
    b. In addition, for molybdenum, further R&D efforts should be devoted to five inherently attractive routes for molybdenum separation, including oxidative roasting followed by sulfuric acid and water leaching, lime-scavenged reduction, pressure oxidative leaching, pyrochlorination and bioleaching.

SUMMARY WP3 – SECONDARY RESOURCES (INDUSTRIAL WASTE, TAILINGS)

INTRODUCTION AND EXPECTED OUTCOME

In WS2 the innovation potentials for recovery of refractory metals from secondary resources (waste rock/tailing and industrial residuals) are presented in two aspects:

1) Innovation potential in mining and re-processing of tailings. Only molybdenum and tungsten tailings are presented, as for the other elements there is no primary resources available.
2) Innovation potential in the recovery of refractory metals from secondary resources. The involved processes include pyro-, hydro- and even bio-metallurgical processes, and in some cases the pyro- and hydro-metallurgical process are combined in one process route.

The innovative technologies presented during WS2 are mainly based on the literature survey and the partners' own project experience, the former of which may not be evaluated with respect to their economic feasibility for industrial application in EU. Feedbacks and comments were obtained from the consulting experts as well as the other attendees.

KEY FINDINGS

MINING AND REPROCESSING OF TUNGSTEN- AND MOLYBDENUM-CONTAINING WASTE ROCK/TAILINGS

The historical disposed waste rock and tailings can, in general, be mined and processed by using similar methods as for primary mines. However, due to the low concentration of tungsten and molybdenum in these materials, the main focus is on the development of enrichment technologies. Several innovative enrichment technologies, such as centrifugal separation and high gradient magnetic separation, are introduced in the presentation and D3.3 report; however, it is still doubtable that these technologies can be economically applied in the industrial scale.

Due to the co-existence of refractory metals with other valuable metals, a comprehensive recovery of other metals from waste rock and tailings can increase the incentives for recovery.

Due to the comparable low price of molybdenum at the moment, it is difficult to foresee an implementation of recovering molybdenum from low grade ore alone in waste rock and tailing, unless there are other incentives, such as environment pressure from the authorities.

INNOVATION POTENTIAL IN THE RECOVERY OF MOLYBDENUM

Due to the fact that molybdenum is largely used to produce steels, the main source of molybdenum-containing secondary resource is identified as mill scale from the hot metal working process of molybdenum-containing steels. Three innovative processes for recovering molybdenum from mill scale were presented and discussed.

1) Molybdenum-containing mill scale can be made into briquettes together with carbonaceous materials and the briquettes can be charged into Electric Arc Furnace (EAF). During the smelting, the mill scale can be reduced and molybdenum is recovered in the final steel.
2) Mill scale can be mixed with carbonaceous materials and be reduced in a microwave heater. The molybdenum is recovered in the formed metal beads, which can be used for molybdenum-containing steel production.
3) Due to the high iron content in the mill scale, the mill scale can be used for iron powder or direct reduced iron (DRI) production. If molybdenum-containing mill scale is used, the formed product would be molybdenum pre-alloyed iron powder or DRI, which can be used as feed for the powder metallurgy process or for EAF steelmaking of molybdenum-containing steels.

Besides primary ore, molybdenum also exists in copper-molybdenum ore. During the smelting extraction of copper and molybdenum is lost in the copper slag, which has similar grade of molybdenum as that of the primary molybdenum ore. Two innovative processes for recovering molybdenum from copper slag were presented and discussed.

1) Molybdenum in the copper slag can be extracted by carbothermic reduction with the addition of flux materials (CaO and Al_2O_3). The formed Fe-Mo-C alloy can be used for special steel production while the formed Al_2O_3-CaO-SiO_2 slag can be used as raw material in cement production.
2) Due to the fact that the molybdenum exists in the copper slag in the form of 2FeO•MoO_2 - Fe_3O_4 spinel. Direct leaching copper slag to extract molybdenum is not efficient. However, when copper slag is subjected to oxidative roasting and consequently selective leaching by H_2SO_4, more than 80 wt.% molybdenum can be recovered.

The other molybdenum-containing residual material includes dusts from the steelmaking process. By following a leaching process the molybdenum in the dusts can be recovered. Similarly to mill scale, the molybdenum in the dusts can also be recovered by carbothermic reduction in the EAF.

So far, there is no technical hinder for the recovery of molybdenum from the above-mentioned secondary materials. On the global level there has been an abundance of primary molybdenum resources. The molybdenum recovery from these materials has little interest to the industry, unless the molybdenum content in these materials (such as mill scale from high Mo-alloyed steels) are very high or if other valuable metals of interest to extract also are involved in these materials. However, the environmental concerns can be the incentives for the recovery of molybdenum from some of these materials in the future.

INNOVATION POTENTIAL IN THE RECOVERY OF TUNGSTEN

Secondary resources of tungsten include waste rock/tailings, mill scale, grinding dusts/sludge, etc. Due to the high price of tungsten, some of the industrial residuals are recycled in-house directly by the processors. Several innovative processing technologies have been introduced as the following; however, it is not yet clear that these innovative processes can be economically feasible.

1) Due to some disadvantages (high temperature and large amounts of reagents) of the existing technology for extracting tungsten from tungsten ore, an innovative process was developed including leaching the ore with phosphoric and nitric acid. The formed acid solution can be used to extract tungsten compounds by solvent extraction. High recovery degree of tungsten and low amount of waste water generation can be expected.
2) Biosorption, emulsion liquid membrane techniques and micro-structured extraction process are introduced as three innovative processes to replace the traditional solvent extraction process.

So far, tungsten recycling is not restricted by technological availability. The main barrier of the tungsten recovery is the lack of collection infrastructure and affordable collection route for the residuals that, as of now, are not recycled.

INNOVATION POTENTIAL IN THE RECOVERY OF NIOBIUM AND TANTALUM

Tin slag and copper smelting slag are examples of secondary resources containing niobium and tantalum. Due to the similarities in behaviour of the two elements and that the two elements in many cases coexist; the methods used for extraction of niobium can be employed to extract tantalum. During the presentation, the innovative aspects on solvent extraction are introduced and several case studies were carried out and shown as the following:

1) Extraction of niobium and tantalum from Tin slag (both low grade and high grade);
2) Extraction of niobium and tantalum from copper smelting slag;
3) Extraction of tantalum from Ni-Ti-Fe-concentrates;
4) Extraction of niobium from Bayan Obo tailings;
5) Extraction of tantalum from alloy scrap;
6) Extraction of niobium and tantalum from WC sludge.

Some of the introduced innovative processes are based on the lab-scale investigations, in other words, not proved by pilot-scale trials. Further, some of the secondary materials are not available or may be difficult to collect for EU production, such as Bayan Obo tailings.

INNOVATION POTENTIAL IN THE RECOVERY OF RHENIUM

Dusts and gases from copper/molybdenum production are the main source of rhenium; the other sources can be residuals from lead production and Fe-As alloy production. The innovation potential in the development of solvent extraction and ion exchange processes are presented. Several case studies from the literature are given:

- Rhenium extraction as by-product from copper/molybdenum production;
- Recovery of rhenium and molybdenum from pressure oxidation molybdenite leachate;
- Recovery of molybdenum and rhenium from copper shaft residue;
- Rhenium extraction from spent catalysts;
- Rhenium extraction from Fe-As alloys.

The presented innovative technologies are case-based; the future development of the potential technology will be dependent on the availability of these secondary materials for EU production.

CONCLUSIONS

INNOVATION POTENTIAL OF RECOVERING REFRACTORY METALS FROM SECONDARY RESOURCES

The state of the art of methods for recovering refractory metals from secondary materials involves uncertainties that need to be clarified in order to fully judging the innovation potential correctly. This concerns following:

- Value chain data, especially quantification;
- Quality and amount of secondary materials available for EU production;
- Knowledge on feasibility to recover several elements in the same processing route as for refractory metals and its impact on the economy;
- Economic potential for recovery of refractory metals from secondary resources.

Moreover, the availability of primary resources, their price, quality and processing route will also have impact on the recovery of refractory metals from secondary resources. As these factors, in general, varies quite a lot over time they can be difficult to predict. In some cases, political decisions on allowance for intermediate storage or landfill as well as taxes can be the driving force for increased recovery. It is required that a substantial ratio of the residue can be recovered otherwise the impact on landfill costs will be minor. After extraction of the desired refractory metals and possible other metals it is a great advantage if the major bulk of residue can be used e.g. as construction materials, as energy source, as slag former, etc.

From the survey, it is found that secondary resources of tungsten, tantalum, niobium, rhenium and molybdenum are existent in Europe, sometimes some of these elements co-exist. In most cases, there are existing hydro-metallurgical and pyro-metallurgical methods which can be used but these methods need to be optimised and combined in a feasible way. The main problem with the secondary resources is that they are dispersed over many different locations. The refractory metals are often diluted and large volumes have to be treated for recovering a moderate amount of the specific metal. The recycling costs might be a hinder and these costs become higher with need for collection and diluted materials. Additionally, there is lack of collection infrastructure.

REFRACTORY METAL SPECIFIC CONCLUSIONS

TUNGSTEN

Tungsten overall has a quite high recovery rate from mill scale and steel making dust as well as from fines generated during manufacturing of products. There is however available resources from mining and quarrying activities in Europe. Existing storages from historical mining can in general be treated in similar way as primary raw material. Promising technologies are available but there are needs for optimization and customization of the processes. Moreover, the collection of tailings and need for pre-treatment and movement as well as economic aspects is of great importance.

NIOBIUM AND TANTALUM

Niobium and tantalum have similar chemical properties and may be found together in the residual materials. Due to the chemical similarities of elements most processes developed for niobium can be equally employed for tantalum. There are several innovative processes that have been reported in D 3.3 but all processes are not tested on pilot scale, in some cases the information on maturity of processes is missing. Additionally, the technical-economic analysis is often missing and it is difficult to compare the potential benefits of new processes with the current industrial processes, hence further investigations is needed.

Barriers in current processing are:

- Non-selective leaching resulting in large amounts of impurities also being dissolved;
- Current extractants used in SX processes are not optimized for specific application;
- Environmental issues are associated to the use of HF and fluorides, therefore alternatives should be desirable;
- The extraction leads to generation of substantial solid wastes;
- Niobium and tantalum can be easily get oxidized and are therefore often lost in slags.

The need for innovation includes:

- Improved selectivity for processing and leaching techniques to increase the niobium/tantalum concentrations;
- Development of leaching and solvent extraction processes without need for HF and fluorides;
- Development of more robust extractants with higher efficiency in non-fluoride media;
- Increased recycling of effluents to reduce liquid and solid waste, this may need development of purification steps for the chemicals;
- Development of combined, well adapted hydro- and pyro-metallurgical processes.

RHENIUM

Several secondary resources of rhenium were stated as:

- Washing acids from copper and molybdenum industry (already in use);

- Copper shaft furnace residue;
- Dusts and slimes from plumbum production;
- Fe-As alloys;
- Copper heap leaching PLS, molybdenum pressure oxidation PLS;
- Spent catalysts.

There are conventional separation methods using strong ion exchange with Purolite resins (weak anion exchangers and solvent extraction with tertiary amines). Based on discussion, agreement was reached confirming that ion exchange is used when c_{Re} = 1…100 ppm and solvent extraction is to be used when c_{Re} = several g/L. The innovation potential includes the development of cheaper solvent extraction reagents and especially ion exchange materials. Finally, feasibility improvement e.g. from process configuration optimization, lower waste amounts, more durable and environmental friendly separation materials needs benefits from innovation.

MOLYBDENUM

Molybdenum in mill scale is recycled within the steel plants but not specifically for recovery of molybdenum, except for in case of high Mo-alloyed steel. There is molybdenum in copper slag that potentially could be recycled, but due to low value of molybdenum makes it difficult to economically develop and implement methods for recovery of molybdenum, only in case of costs connected to landfill, landfill taxes, etc.

FUTURE WORK

There is need to ensure the quality of the existing data and knowledge gathered and also:

- Identifying the most promising secondary resources of refractory materials available for EU production as well as their quality and specification;
- Identifying the promising innovation potential to recover the selected refractory materials;
- Identifying the economic feasibility for recovering refractory metals from selected secondary resources by considering as well the environmental impacts of these secondary resources;
- Closing the cycle by considering using the residual materials after recovery of metals as by-products other than wastes.

SUMMARY WP4 – SECONDARY RESOURCES (URBAN MINING)

INTRODUCTION AND EXPECTED OUTCOME

In preparation to the WS2 partners involved in WP4 focused their activities on identification of barriers to refractory metals recycling and measures of remedy for effective recycling, determination of applications where recycling may present a significant opportunity, determination of promising new approaches and solutions (both technological and non-technological) which may lead to increase of recycling rates. In the results, Deliverable 4.3 "Innovation potential in the recovery of refractory metals from urban mines" was prepared, consisting of reports on individual refractory metals, i.e. rhenium, niobium, molybdenum, tungsten and tantalum, where a broader approach to the problem of recycling of refractory metals from end-of-life products was taken to describe the innovation potential taking into account factors affecting both collection of end-of-life products and extraction of the metal value from the collected materials.

One of the main objectives of the report was to provide the participating in WS2 experts and stakeholders with current and reliable background information for discussion of potential pathways for optimization of the balance between resource availability and usage.

KEY FINDINGS

BARRIERS

The current situation in recycling of refractory metals is far from satisfactory and the following main factors that hinder higher metal recyclability were identified:

- Product design that makes disassembly and material separation difficult or impossible;
- High product mobility across the globe, which has a tendency to move products from countries with higher recyclability to countries with lower recyclability;
- A lack of social and economic awareness of the loss of resources due to the low intrinsic value of products by unit;
- Lack of recycling infrastructure;
- Recycling technology has not kept pace with the complexity and diversity of modern products.

SOLUTIONS

The circular economy philosophy provides very promising approach for successful resolving of the low recycling rate problems. It is clear that in the 21st century recycling needs acceleration, because the variety and complexity of applications with metals is increasing.

More and more countries in the world face rapidly growing waste flows for which they have no appropriate recycling infrastructure. Therefore, enhanced technology transfer and international cooperation should be decisively accelerated by international recycling conferences, technological implementation programs in emerging economies and developing countries, and specific scientific exchange programs.

Refractory metals logistic chains should be identified and quantified across Europe, mapping net availability, consumption and demand as well as potential supply gaps. The chains should also be expanded to include a circular economy mindset with end of life recycling aspects.

Novel business model for the enlargement of e-waste refractory metals recycling should be developed for SMEs in targeted regions of Europe by, for example, development of region specific business plans for refractory metals recycling in cooperation with local authorities and recycling networks.
Development of region specific business plans for the enlargement of the SME e-waste refractory metals recycling along with the SMEs as well as with local authorities and recycling networks should be pursued. Innovative region specific ways of increasing e-waste collection rates should be studied and set the guidelines for the rest.

CONCLUSIONS

Based on the performed analysis, the following element specific conclusions with respect to lack of information and needs for research and development have been drawn:

Information gaps:

- There is no sufficient data available on processes of tantalum recovery and their potential industrial implementation;
- There is a need to come up with an inventory of tungsten, niobium presence in used electronics in concentration big enough for recycling;
- There is need for identification of new applications (e.g. rhenium in coatings) which may present future sources of refractory metals.

R&D needs:

- Development of sensor sorting technologies: separation of fractions from WEEE (mainly PCBs) enriched in tantalum and probably niobium & tungsten;

- Development of new procedures and tools to implement collection of steel scrap based on composition which should lead to minimization of molybdenum, niobium losses in re-melting;
- Development of cost effective, flexible hydro-processes for refractory metals recovery from multicomponent alloys (e.g. super alloys);
- Upscaling of promising and innovative technologies for refractory metals recovery for validation of newly developed processes.

FUTURE WORK

In the final stage of WP4 the activities will be focused on evaluation of the environmental impact of the technologies for recovery of refractory metals from end-of-life products. To address the problem in an adequate way the Life Cycle Thinking approach will be included taking under consideration the current waste management and the waste management required for future recovery of refractory metals from urban mining streams. The results will be collected in the final WP4 Deliverable 4.4 "Management of waste from urban mines processing: identification, environmental evaluations".

SUMMARY WP5 - SUBSTITUTION

INTRODUCTION AND EXPECTED OUTCOME

OBJECTIVES

The objective in WP5 is to discuss and analyze the map of substitution for refractory metals within their most relevant applications in EU industry according to threefold criterion of social, economic and strategic importance and evaluate the substitution potential throughout the refractory value chains. A holistic approach will be used considering four scenarios:

1) Potential to substitute the refractory metal, paying special attention to existing technological barriers, and/or reduce its use in considerable volume (D5.1);

2) The potential and realistic (present high TRL) substitutes will be evaluated in order to maintain demand in current consumption level (D5.2);

3) The scenario that the present usage continues, no potential substitutes are found, and refractory metal demand will increase (D5.2).

4) The refractories will substitute the less performing elements in large amounts. (D5.2)

WP5 aims for evaluating the substitution potential and impact creating the understanding of the substitution potential of selected refractory metals in both ways (decrease and increase) throughout the refractory value chains.

In Task 5.1, the state of art of refractory metal application volumes forwarded by the cumulative impact of first scenario evaluation: Potential to substitute refractory metals, and/or reduce the use of the metals in considerable volume will be summarized.

In Task 5.2, other scenarios: (2) the potential and realistic substitutes will be found in order to maintain demand in current level versus potential of usage increase, (3) the scenario of the present usage continues, no potential substitutes are found and refractory metal demand will increase and (4) the refractories will substitute the less performing elements in large amounts, will be evaluated and summarized.

OUTCOMES

The work is ongoing in WP5 and presentations showed in WS2 present only preliminary results. All the final results will be reported in upcoming deliverables. The first deliverable: D5.1.Report on refractory metal reduction potential –potential substitutes will be submitted 31 October 2016. The second deliverable: D5.2. Report on Refractory metal increase potential – substitute’s non-refractory metals, will be submitted 31 December 2016.

KEY FINDINGS

APPLICATIONS AND THEIR VOLUMES

The work in WP5 has been started by evaluating the applications (forms of metal and its end uses applications) and their volumes (consumption share in products) of each refractory metal (niobium, tantalum, rhenium, molybdenum and tungsten). The role of each refractory metal in certain application has been evaluated and identifying the properties why refractory metals are used.

For each refractory metal it has been also gathered state of art data about their abundance, global distribution, global production and consumption. Sustainability characteristics including relative supply risk, recycling rate and substitutability were also screened in order to evaluate the substitution potential.

NIOBIUM

The main consumption of niobium is as ferroniobium in steels[1]. Niobium is used because of grain refinement and precipitation hardening resulting in increased mechanical strength, toughness, high-temperature strength, and corrosion resistance. Major consumers are Automotive, Construction and Energy industries[2]. Niobium is also used in super alloys because of its high temperature performance. Major consumers are in Aerospace industry.

TANTALUM

The main consumption of tantalum is in electronic devices mainly in capacitors as tantalum powder or tantalum wire. Tantalum is used because of its high and temperature insensitive volumetric capacitance. Other applications are e.g. tantalum carbide in cutting tools, tantalum sheets, plates, rods and wires in high-temperature alloys, in process equipment and prosthetic devices[3]. Tantalum offers high resistance to corrosion and high temperatures.

RHENIUM

The main consumption of rhenium is in super alloys because of increase HT creep strength[4]. Major consumers are in aviation industry. Rhenium in catalysts results in operating at lower pressures and

[1] Annex V to the Report of the Ad-hoc Working Group on defining critical raw materials, version of 30 July 2010.
[2] USGS Mineral Resources Program. Niobium and Tantalum—Indispensable Twins. s.l. : U.S. Geological Survey, 2014

[3] T.I.C, TANTALUM-NIOBIUM INTERNATIONAL STUDY CENTER 2016
[4] USGS Minerals Information. Rhenium statistics and Information, 2016 http://minerals.usgs.gov/minerals/pubs/commodity/rhenium/

higher temperatures[5]. Major consumers are in automotive industry. Rhenium provides erosion resistance to components in high-temperature rocket engines and hot gas valves.

MOLYBDENUM

The main consumption of molybdenum is as molybdenum oxide in steels to increase strength, hardness, electrical conductivity and resistance to corrosion and wear[6]. Major consumers are in automotive, mechanical engineering, building&construction, aerospace&defence. Molybdenum-based catalysts are used in the petroleum and plastics industries because of their resistant to sulfur poisoning. Molybdenum-based pigments are stable and inhibit corrosion[7].

TUNGSTEN

The most important usage of tungsten today is in cemented carbides (hard metals). The main constituent is tungsten carbide (WC). Tungsten carbides play a crucial role as they combine high hardness and strength with good toughness within a wide property range, and thus constitute the most versatile hard materials group for engineering and tooling applications. Tungsten is also used in steel alloys because tungsten significantly improves the hot hardness and hot strength of steel and leads to increased yield strength and tensile strength without adversely affecting ductility and fracture toughness. In super alloys tungsten is used because of its high temperature strength, high thermal fatigue resistance, food oxidation resistance, excellent hot corrosion resistance, air melting capability tungsten alloyed nickel- and cobalt-based super alloys are used in aircraft engines, marine vehicle, turbine blades and vanes, exhaust gas assemblies and as construction material for furnace parts. In mill products tungsten is used because of its extremely high melting temperature (3414 ºC), low vapour pressure, high stiffness and excellent creep resistance at elevated temperature. Tungsten used in the form of wires, coils and coiled coils incandescent lamps and as electrode in low-and high pressure discharge lamps.

POTENTIAL SUBSTITUTES

NIOBIUM

EU consumption of niobium is approximately 24% of global niobium consumption. There is no primary niobium production in Europe so scrap is the only available intra-European raw material source. So there is need to recycle and find potential substitutes to satisfy increased demand.

[5] http://www.afs.enea.it/project/oldprojects/protosphera/Proto-Sphera_Full_Documents/PROTO-SPHERA_CATIA/Prova_Modulo/5E379d01.pdf, http://www.platinum.matthey.com/about-pgm/applications/industrial/petroleum

[6] **USGS Minerals Information.** Molybdenum statistics and Information, 2004-2015 http://minerals.usgs.gov/minerals/pubs/commodity/molybdenum/

[7] International Molybdenum Association [online] http://www.imoa.info/molybdenum-uses/molybdenum-uses.php

Understanding the role of niobium in steels is crucial in order to evaluate the potential substitutes. Niobium reacts in steel with carbon to form nanometer-sized NbC-precipitates which decreases grain size resulting increase in strength and toughness[8]. Potential (partial) substitutes for niobium in steels are titanium & molybdenum and vanadium & molybdenum combinations[9].

TANTALUM

For tantalum main application, capacitors, possible substitutes are aluminum and ceramics based capacitors and they are likely to answer the most common needs[10] [11] [12] [13]. Tantalum capacitors are still used in applications which require high performance. In other application areas there is possible substitution of tantalum by niobium. In cemented carbides also titanium carbides (TiC) and nitride (TiN) are possible. In corrosion-resistant equipment glass, platinum, titanium, and zirconium are possible substitutes. In high-temperature applications hafnium, iridium, molybdenum, rhenium, and tungsten are possible.

RHENIUM

There are no primary rhenium production, a by-product of copper and molybdenum mining. Supply depends on mining economy of major metal (i.e. copper). There exist high degree of economic importance, but a relatively low level of supply risk. Supply risk metric - level of concentration or political stability of producing countries.

MOLYBDENUM

Molybdenum production is 50% primary and 50% a by-product of copper mining. It partially depends on mining economy of major metal (i.e. copper). It has moderate economic importance being non-critical metal. High level of supply risk strongly connected with low political stability of top producer and top reserve holder.

For most applications (87%) molybdenum have high substitutability index. Thus there is little substitution for molybdenum in major application as an alloying element in steels and cast irons. The reason for this is that the availability and versatility of molybdenum lead to development of new materials that benefit from the alloying properties of molybdenum. Potential substitutes for molybdenum include boron, chromium, niobium and vanadium in alloy steels; tungsten in tool steels; graphite, tantalum, and tungsten for refractory materials in high-temperature electric furnaces. For material strengthening and refractory properties, niobium could substitute (lower and stable prices,

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[8] R. Okamoto, A. Borgenstam, J. Ågren, Interphase precipitation in niobium-microalloyed steels, Acta Materialia 58 (2010) 4783–4790

[9] Seto, K., Funakawa, Y., and Kaneko, S., "*Hot rolled high strength steels for suspension and chassis parts "NanoHiten" and "BHT" steel*", JFE Technical Report, No. 10, December 2007.

[10] CRM_Innonet, Substitution of critical raw materials, http://cdn.awsripple.com/www.criticalrawmaterials.eu/uploads/D3.3-Raw-Materials-Profiles1.pdf

[11] *Granta CES Selector 2015*

[12] *European Commission*, 2014. REPORT ON CRITICAL RAW MATERIALS FOR THE EU NON-CRITICAL RAW MATERIALS PROFILES

[13] U.S. Geological Survey, Mineral Commodity Summaries, January 2015

niobium is the lightest of the refractory metals, niobium is unique in that it can be worked through annealing to achieve a wide range of strength and elasticity). As potential substitutes for molybdenum in catalysts ruthenium, nickel, cobalt and tungsten can be used.

TUNGSTEN

Tungsten Supply Risk Index is rated very high 9.5. The consumption of tungsten continues to increase as the amount of carbides tool production increases with the expansion of markets in developing countries.

For tungsten main application, tungsten carbide-based cemented carbides, tungsten is difficult to substitute without increase of cost or lower performance. Titanium carbides (TiC) and titanium nitride (TiN) are potential substitute but the technology is not competitive at the moment. In super alloys in some applications tungsten could be substituted by Ceramic matrix composites (CMCs) made from a silicon carbide/nitride matrix for gas turbine engines. Nanostructured n-alloys are also possible (but TRL is still low 3-4) – 10 y scenario. Tungsten is difficult to replace in some mill products. In lightning equipment tungsten filaments can be substituted by carbon nanotube filaments, light-emitting diodes or other light sources. Steel products tungsten can be replaced by other CRM (niobium) or refractory metals (molybdenum).

CONCLUSIONS

The work is ongoing in WP5 and presentations showed in WS2 present only preliminary results. All the final results will be reported in upcoming deliverables.

Substitutes for refractory metals exist but typically with loss of performance or increase in cost. Typically substitutes are other refractory metals or other critical raw materials, CRMs (e.g. in steel products) which could substitute refractory metals in performance but are not sustainable choices for substitutes.

Long term research (-10years) investment is needed for technology leap in new material development to develop sustainable substitutes for refractory metals. Low TRL level development e.g. ongoing H2020-FETOPEN-2014-2015-ICARUS-GA713514- New nanocrystalline tailored alloys under extreme conditions.

FUTURE WORK

Future work concentrates finalizing the deliverables: D5.1.Report on refractory metal reduction potential –potential substitutes and D5.2. Report on Refractory metal increase potential – substitute’s non-refractory metals.

According to feedback in WS2 in upcoming deliverables in WP5 it will be concentrated to update the substitutability for refractory metals, possible substitute's advantages and drawbacks. The role of refractory metals in certain applications will be evaluated in order to understand the possibilities of potential substitutes.

FEEDBACK FROM EXPERTS

The experts who attended the workshop were asked to give feedback regarding the information and conclusions presented during the workshop, with a particular focus on the missing information/actors/stakeholders. To this end, summaries of the WP sessions as described in the above chapters were sent to the experts along with the following questions:

1. Which relevant information/actors/stakeholders do you think were missing?
2. Which relevant sources of information/actors/stakeholders should we consider (please give reference if possible)?
3. Particular comments to WP summaries
4. Other comments/suggestions

The feedback received from the experts regarding each of the questions is summarized as follows:

1. Which relevant information/actors/stakeholders do you think were missing?

In general, experts think that more deepening and detailed information should be provided regarding the following topics:

- Continuous processing, as process flowsheets from articles often show experimental knowledge from batch experiments and lack information about possible troublemaking effects and phenomena in real process,
- Process flowsheets and data necessary for eco-efficiency analysis (economic and LCA data),
- In the analysis of potential raw material resources for refractory metals, deep sea mining should be taken into account,
- Substitution need to be further developed.
- Information related with future mining and potential use of advance ICT tools and technology in mining of refractory metal, including the impact of safety.

Most experts have identified industry stakeholders as potential sources of valuable information, particular suggestions are as follows:

- More industry players should attend and present at the workshops as invited guests for them to give the overall industry perspective to the group and the research teams, e.g. Umicore experts could provide some relevant insight to help with the project, especially due to them being close to the EC.
- Interviews with experts from relevant industries to get some qualitative information, e.g. their forecast about market and technology trends, R&D orientations, possible effects of implementing batch experiments or pilot trials in the real process, etc.

2. Which relevant sources of information/actors/stakeholders should we consider (please give reference if possible)?

In general, experts consider that project has a well-recognized base of potential players and stakeholders so it has sufficient technical and research capabilities to generate the information needed without having to rely on third parties such as Roskill. On the other hand, they also question the capacity of Roskill to provide precise data on Europe due to the very small amount of actors for each metal that involves that each actor keeps his numbers secret.

Anyway, additional information can be obtained from the following sources:

- Review of new patent applications in the field of processing of refractory metals,
- H2020 community and project networking, particularly on substitution,
- Knowledge and Innovation Communities (KICs) stakeholders,
- Metals associations: International Zinc Association, etc.
- European Commission (2015), Study on Data for a Raw Material System Analysis: Roadmap and Test of the Fully Operational MSA for Raw Materials, Report prepared by BIO by Deloitte for the European Commission, DG GROW, November 2015, 179 p[14].
- Other ongoing studies, e.g. study on R&D on 20 metals under development by ADEME.

3. Particular comments to WP summaries

The experts consider that WP summaries are well structured and provide with valuable information. Charts and figures are recommended to illustrate matters; in particular, a sectoral value chain approach with flows should be produced for each WP. After that, a more general value chain may be produced by integrating the sectoral WPs value chains.

A standard "template" based on the type and form of the data to be presented is recommended to be utilised by the whole project and consistent across the various metals under investigation.

4. Other comments/suggestions

Regarding the organization of the workshop, experts suggest to keep the workshop and deliveries short and compact, making sure to only include the most important findings. To this end, each WP leader may present the whole work package instead of many partners presenting on during the same session. This would make partners have to prepare the global presentation and agree on the final messages. The presentations would be more consistent and look better for any funding stakeholder (European Commission Representatives etc.). The progress of work packages may be represented by simple traffic lights (Green – on track on target, Yellow – warning of some issues down the track, Red – delay in progress due to specific issues).

Other suggestions brought forth by experts include:

- Consideration of a MSP REFRAM Business Plan approach, i.e. the vision, strategy and actions towards all the partners need to direct their endeavors to build the overall project.
- Recording presentations to make an MP4 video or a youtube file that could be useful for the ones not attending the workshop.
- Coordination of the experts to meet and compare notes and then come back with ideas that may not have been brought up during the first presentations.

[14] https://ec.europa.eu/growth/tools-databases/msa/sites/default/files/deliverables/MSA_Final_Report.pdf.