bitious, research project that is well interconnected with other researchers and disciplines, 2) a close collaboration with participant labs working in a complementary research field where he/she is seconded for at least one month, and 3) training in soft skills. This structured training stimulates both the creativity and the entrepreneurial mind-set of the researchers at the doctoral level. The composition of the consortium guarantees a public/private-sector collaboration on the research training, with the acquisition of the key skills needed in both the public and private sectors. The research training within COSMIC, dedicated to process intensification and the application of ultrasound- and microwave-enhanced flow processes for organic and nanoparticle synthesis, is both unique and innovative.

2.2.2 Towards the long-term sustainability of the network

COSMIC not only aims at new developments in the medium term in flow chemistry and external energy actuation, but also at strengthening the process-intensification professional networks at the EU level (incl. the EFCE Working Party on Process Intensification, the Intensified Flow Separator Infrastructure and Expertise (INSPIRE) Network of Infrastructure funded by the EIT-KIC Raw Materials) and other current EU projects such as ERC grants (Simon Kuhn's Starting Grant: MicroParticleControl and Jesús Santamaría's Advanced Grant: HECTOR), MSCA-ETNs (Photo4Future, RENESENG and HUGS) and the H2020 research projects (e.g., ADREM, US4GREENCHEM, CONSENS, PRINTCR3DIT, COSMOS, WASTE2FUELS). COSMIC, which can also draw on a number of large, nationally funded R&D projects (e.g., several UK-EPSRC projects on microreactors and flow technology, the Flemish FWO-Odysseus project on microfluidics and ultrasound), targets a long-lasting frame for its cooperation, going well beyond the EU-financed project phase, which will convert COSMIC into a lasting, structured training programme. The motivation for this is that safeguarding a sustainable network interest in process intensification, flow chemistry and alternative energy actuators is of vital importance for the long-term future of COSMIC's industry participants. In order to organise this transition smoothly, in the coming years COSMIC plans to:

- continuously improve the COSMIC website;
- reserve a specific time slot during the Network-Wide Events for *brainstorming discussions* between senior and young researchers with the joint aim of training ESRs in an open-mind use of their scientific results and to make an early discovery of possible new uses for their results, which can lead to new projects and collaborations extending the specific project;
- formalise joint training programmes (e.g., COST) in active cooperation with the EFCE Working Party on Process Intensification.

2.2.3 Strengthening European innovation capacity

COSMIC has several participants that demonstrate high levels of entrepreneurship. The 2 industrial Beneficiaries and the 3 industrial Partner Organisations are entrepreneurial champions in their respective fields of expertise. To give only three illustrative examples: Arkema is involved in two process-related SPIRE projects (PRINTCR3DIT on design of structured reactors for process intensification; CONSENS on integrated control and sensing), Microinnova has recently won the EFCE Process Intensification Award 2015 for Industrial Innovation with its innovation "Flow Miniplant, a toolbox that boosts process performance to a new level" and Sairem is the only microwave specialist in the world that can design custom-made components or engineer complete solutions, provide support for all aspects of customers' go-to-market strategy, from prototype to production, select cost-effective components, test prototypes and assemblies, and manufacture the highest-quality solutions. The academic participants have a lot of experience with spin-offs (e.g., Rafa Luque's Green Applied Solutions (http://www.greenappliedsolutions.com.es/company.html), patenting and scale-up of processes (e.g., Georgios Stefanidis is involved in the "Re-Inventing The Toilet" project, funded by The Bill and Melinda Gates Foundation).

The mobility of the ESRs has great benefits for the European Research Area. All involved parties (ESRs, universities and companies) benefit from the knowledge exchange, and gain from the sharing of teaching and learning expertise. By developing expertise and collaborating on cutting-edge research, the industrial participants will be in an excellent position to take a leading role in the development of innovative technologies.

The different companies' and academic participants' scientific infrastructure provides the ESRs with the best conditions to acquire a wide range of best-in-class competencies, both technical and non-technical. These technical competencies include organic synthesis procedures, nanocatalyst preparation and screening, ultrasound and microwave actuation, flow chemistry and microfluidics, as well as technical and environmental assessment methodologies. The non-technical competencies relate to working in a program-managed research environment, developing products and processes through open-innovation strategies, while capturing, evaluating and safe-guarding intellectual property through patents. The training that the ESRs receive makes them attractive to other universities and industries all over Europe, ensuring effective knowledge transfer.

2.3 Quality of the proposed measures to exploit and disseminate the project results

2.3.1 Dissemination of the research results

The scientific dissemination targets 1) internal and external scientists (both in academia and industry), as well as 2) national and EU policy makers. The ESRs present their results at the 6-monthly workshops. All these results are then published in international peer-reviewed journals, after due consideration has been given to the protection of intellectual property rights (Exploitation Manager and Dissemination WP Leader advise the SB, which decides), to present the work to the international research community in the fields of continuous processing, ultrasound and microwave chemistry and associated technologies. Following H2020's open-access policy, the consortium ensures that

all peer-reviewed scientific publications resulting from this project are deposited in open-access repositories, e.g., the Lirias repository of KU Leuven (https://lirias.kuleuven.be/). Further dissemination involves international conferences, where each ESR has the opportunity to participate and present their latest results.[30] Dissemination towards industry is performed through publishing of technical brochures, presenting at industrial symposia (e.g., ACHEMA) and via the dissemination and training activities organised by the EFCE Working Party on Process Intensification.

The EU is informed about the results of the research training projects using milestone reports that are delivered at regular intervals by each of the ESRs, assembled by the MST.

2.3.2 Exploitation of results and intellectual property

COSMIC appoints a seasoned Exploitation Manager, P.T. Jones (KU Leuven), with a clear goal to commercially exploit the breakthrough results in the project, irrespective of the Training goals. WP6 is dedicated to this task. The details are presented in Section B3.

2.4 Quality of the proposed measures to communicate the project activities to target audiences

2.4.1 Communication and public engagement strategy of the project

The COSMIC coordinator supervises the main strategy to transfer results to the general public.

COSMIC website. The main public-engagement activity is the development of a new website dedicated to process intensification using alternative energy forms in flow processes, which is closely related and will be linked to the websites of the MSCA-ITN Photo4Future (www.photo-4future.com), the INSPIRE Network of Infrastructure (starts in October 2016), the EFCE Working Party on Process Intensification (www.efce.info/WP_PI) as well as the ESS and AMPERE websites. During the meetings of the Researcher Council, the COSMIC ESRs plan the future development of the website. The website is to contain short videos related to flow, ultrasound and microwave chemistry and technology. The ESRs are co-responsible for the design and maintenance of the website, as well as for the production of the videos. They blog about their research on this website and share their personal opinions on recent developments in the chemical industry, with specific interest in intensified processing. This approach has been successfully applied in FP7 MC-ITN EREAN, coordinated by KU Leuven (EREAN blog: http://erean.eu/wordpress/, with 33 posts and 11,600 page views after only 6 months). The COSMIC website also hosts the internal project website, including the web pages that are only accessible to the ESRs and the project participants. This password-protected part of the website contains all the relevant documents

30 Some examples: *European Process Intensification Conference* (Barcelona 2017, 2019); *Meetings of European Society of Sonochemistry* (2018, 2020); *International Conference on Microwave and High Frequency Heating* (Delft 2017, 2019).

Figure 7. COSMIC phone "app" integrating social media

related to the project. For every ESR, there is a subdirectory, containing the CV, the personal career development plan (PCDP), the project description, publications, presentations, progress reports and information about the training activities.

COSMIC social media. In addition to the COSMIC website and the blogs, the ESRs maintain a Facebook page and use Twitter, LinkedIn, RG etc. For each social media network, an ESR is appointed as being the responsible person. An additional COSMIC phone "app" is developed to connect all the social media tools. A key outreach activity is a drastic improvement of the Wikipedia pages on process intensification and ultrasound- and microwave-assisted flow processes. At this stage there is no page on process intensification. The pages on ultrasound and sonochemistry[31] only briefly discuss the applications and technological aspects of ultrasound processing. In addition, the fact that the ESRs are of different nationalities creates the opportunity to update the Wikipedia pages in different languages with consistent content.

E-learning. A third activity is the collection of free-to-use e-learning resources (web-based broadcasts of lectures at the network-wide events, the COSMIC Summer School and Symposium, mobile learning apps for access anywhere and anytime). These resources are aimed at undergraduate students of chemistry, chemical technology and materials science. The basic objective is to inform and educate university students and their teachers about the importance of process intensification and to attract secondary-school students to the broader chemicals industry. Another aim is to reduce the cost of in-service training at companies by providing them with freely available training and professional development material. The ESRs spread and plan the work during the Researcher Council meetings, with the Women Researchers Council preparing a special entry (see B3).

COSMIC project videos. During the first year of the project an 8-minute promo video is produced, in which the goals, the team and the collaborating participants are presented. During the final 6 months of the project, a second promo video is made, highlighting the project results.

31 Wikipedia page on ultrasound: https://en.wikipedia.org/wiki/Ultrasound#Sonochemistry); Wikipedia page on sonochemistry: https://en.wikipedia.org/wiki/Sonochemistry

B1.2 Quality & innovative aspects of training

B1.2.1 Overview and structure of the training

Size of programme. EURANTES provides unique training to 15 early stage researchers (ESRs), for 540 researcher months. The 15 ESR positions are distributed among 8 Beneficiaries in 5 countries (Belgium: KU Leuven, Campine, UAntwerp; Germany: Aurubis, RWTH; Sweden: LIU; Finland: UHelsinki and The Netherlands: UUtrecht (Figure 5). Additionally, 6 non-academic Partner Organisations are involved, representing 5 countries (The Netherlands: AVR, BASF; Belgium: InsPyro; Finland: Fortum; Germany: PPM; Italy: EC-Joint Research Centre).

A personalised approach. After recruitment, each ESR conducts an individual self-assessment under the guidance of the Recruitment Committee, the Training WP leader and his/her supervisor(s) to identify the expertise, skills, and competences that need to be developed, both for the successful completion of the research project and for later use in a scientific or professional career. The self-assessment is formulated in a Personal Career Development Plan (PCDP). The ESR, the Training WP leader and

Table 3. State of the art and progress beyond the state of the art intended in EURANTES.

	State of the art	Progress beyond the state of the art and innovation
PROJECT	• The EC considers Sb to be one of the most critical raw materials (CRMs), next to the heavy rare earths, because of production monopoly enjoyed by China. Of all CRMs, Sb has the highest expected supply-demand gap over the period 2015–2020.	• The Sb supply risk in the EU is reduced by Sb recovery from secondary products of Cu and Pb refineries in Europe, by recycling Sb from the WEEE plastics fraction, and by processing stibnite from European and Turkish mines.
PROJECT	• Most of the Sb applications are high-volume, low-tech commodity applications (flame retardants (FRs), Sb-lead alloys for lead-acid (LA) batteries, additive in glass production)	• New high-tech speciality applications are developed for Sb: 1) highly selective adsorbents for waste-water treatment and the removal of radionuclides from (TE)NORM; 2) highly active and selective catalysts for the production of chemical intermediates and fine chemicals; 3) all-Sb redox-flow batteries. Ultra-purification of Sb to a purity of up to 6N is a requirement for Sb use in semiconductor applications.
WP1	• The main Sb ore (stibnite, Sb_2S_3) is processed by pyro/ hydrometallurgical routes. Pyrometallurgical routes have a high energy-consumption, create SO_2 off-gas during the roasting process and yield Sb with a purity less than 99%, while the hydrometallurgical routes based on the dissolution of Sb in alkaline solutions creates large volumes of wastewater.	• A closed-loop solvo/ionometallurgical process is developed, based on the oxidative dissolution of stibnite by Fe(III) salts in organic solvents or ionic liquids. Sb is brought into solution as Sb(III), while the sulphide ions are oxidised to elemental sulphur that can be recovered by filtration. An electrochemical step allows Sb recovery in metallic form, while at the same time Fe(II) is reoxidised to Fe(III).
WP1	• Sb metal can only be electrodeposited from aqueous solutions with a very low current efficiency due to hydrogen evolution, and there is a serious risk of forming toxic stibine gas (SbH_3).	• Sb metal can be electrodeposited from organic electrolytes with a current efficiency of >90%, without risking SbH_3 formation.
WP1	• Pb and Cu ores contain significant concentrations of Sb as a minor component. Sb is not recovered and ends up in $PbO-SiO_2$ slag, which is further treated for Pb recovery or just landfilled.	• A dedicated pyro/hydrometallurgical process allows the efficient recovery of Sb during Pb or Cu refining from primary or secondary resources. By purifying the crude sodium antimonate intermediate, high-quality Sb_2O_3 or Sb_2O_5 can be obtained.
WP1	• Sb can be recovered from lead drosses (produced during recycling of LA batteries) by pyrometallurgical evaporation, but the process is not economically viable and the quality is not sufficient for the main applications	• Qualitative and economical processes are developed for the recuperation of Sb from Pb drosses (and other secondary by-products). Vacuum evaporation at low temperatures is used to obtain Sb_2O_3, ready for use in final applications.
WP1	• FRs in plastics are one of the most important applications of Sb, but the recovery rate of Sb from the plastic fraction of WEEE is currently 0% (zero %).	• Sb is recovered from fly ashes generated by incineration of the plastic fraction in WEEE by an innovative microwave-powered rotary kiln for rapid intrinsic heating to selectively evaporate the Sb_2O_3 from the fly ash, followed by recovery of the compound in the condensate.
WP2	• Pyrometallurgical methods cannot produce Sb with a purity of 99% or better. As, Te, Se, Bi, Sn, Pb, Fe, Cu impurities are very difficult to remove. Purification by solvent extraction is under-explored, and mainly focussed on extracting from HCl solutions.	• Sb is purified to a purity of >99.9% (3N) by solvent extraction with undiluted chloride, bromide or iodide ionic liquids. The split-anion extraction approach allows extraction with this ionic liquid from cheaper H_2SO_4 solutions.
WP2	• Ultra-purification methods (e.g., zone refining) are well developed for semiconductor materials such as Si and Ge, but not for Sb.	• Crude Sb is refined to semiconductor grade (6N or better) by a two-step process based on fractional crystallisation, using a static crystalliser followed by a rotating cooling-finger purification process.
WP2	• Hydrous Sb(V) oxide ("antimonic acid") has long been known for its absorptive (ion-exchange) properties, but its redox and photocatalytic properties combined with the possibility to construct mixed Sb metal oxide ion sieves are largely unexplored. Present methods for oxoanion and NORM removal produce large volumes of secondary waste.	• Mixed-metal oxides (SbMMO) are developed into highly versatile, ion-exchange materials for removal of oxoanions (arsenate, antimonate, chromate, selenate) from wastewater and for removal of (TE)NORM from water and mining waste. Photocatalytic properties of Sb_2O_5 are used to develop SbMMO materials for organic and organometallic contaminants in wastewater.
WP2	• The energy density of commercial redox flow batteries (e.g., all-vanadium redox-flow battery) is limited by the solubility of metal salts in water and the fact that one-electron redox processes are used. Battery applications of Sb are restricted to high-temperature molten-metal batteries.	• All-Sb redox-flow batteries are developed, operational at temperatures < 150 °C. New ionic liquid electrolytes with high Sb concentrations (>3M) are developed. Two and three electrons are involved (Sb^{5+}/Sb^{3+} and Sb^{3+}/Sb^{0}), so doubling and tripling the amount of charge present in the electrolyte, and increasing the energy density of the battery, which is crucial for storage of renewable energy.
WP2	• The main catalytic application of Sb is the use of Sb_2O_3 for the synthesis of PET polymers. Other Sb-based catalysts are too expensive for industrial use. Knowledge of the mechanism for Sb catalysts is very limited.	• Industrially relevant, selective and cheap Sb-based catalysts are developed: Sb_2Se_3 catalysts for the catalytic reduction of *p*-nitrophenol into *p*-aminophenol, and Sb-promoted metal oxide catalysts for 3 catalytic reactions. 1) Selective catalytic reduction (SCR) of NO_x with NH_3, 2) Propane (non-) oxidative dehydrogenation to propylene and 3) Propylene oxidation to acrolein. *Operando* studies with advanced *in-situ* spectroscopic techniques give insight in mechanisms.

EURANTES – ETN

WP3	• Resource efficiency indicators mainly on the macro-level (such as DMC) and extrapolating historical data. • Limited studies on statistical entropy, mainly on recycling. • Current models for SFA and resource efficiency based on quantitative methods.	• Forecast of future stocks of Sb secondary resources, accounting for variable product designs and lifetimes. • Resource-efficiency indicator for comparison of primary and secondary resources, applied for Sb. • Resource-efficiency indicator based on resource quality, not only quantity
WP3	• Economic models are not linked to technologies. • Uncertainty is not considered in detail. • Profitability drivers are not well known.	• Using energy and mass balance sheets, an integrated techno-economic model with a high TRL is developed. • Detailed uncertainty and sensitivity analysis using relevant economic indicators. • Profitability drivers of different routes are estimated and the relevant drivers regarding markets, technology and policy are identified.
WP3	• LCA primary Sb production in China: mining processes contribute > 85% of the total impact from extraction to refined material production. Sb one of the top 3 metals with the highest climate-change impact per produced unit. • Local risks not handled in detail	• LCA of both primary and secondary Sb production in Europe, which can be used to find the most promising route to secure European Sb production • Local risks included in the assessment

the supervisor(s) discuss the PCDP regularly, and adapt it when necessary. Following this PCDP, the ESR develops a tailored network-training programme. This training programme consists of: 1) local expert training through research; 2) network-wide training (with recognised credits) by workshops, Winter School, conferences and S/T secondments; and 3) complementary training in generic and transferable skills, partly individual, partly through the host institute's doctoral school, partly through network-wide activities and secondments (Figure 6). The evolution of the research and training programme is assessed on the basis of annual progress reports. Good scientific conduct is one of the cornerstones of the programme.

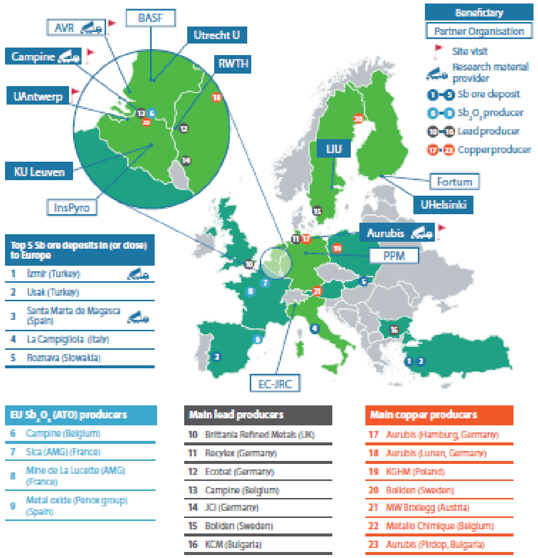

Figure 5. EURANTES Consortium: 8 Beneficiaries and 6 Partner Organisations. Site visits and access to research material as shown, along with the EU-wide character of EURANTES.

1) Expert training through research. EURANTES training complies with the training needs for scientists/engineers working in the raw-materials industry. The projects have a well-defined research/training content, obtained through four brainstorming sessions in the build-up to this proposal. While the ESRs are funded for 36 months in ETNs, the duration of the EURANTES PhDs is to be approximately 48 months (typical duration in most countries). Therefore, all the Beneficiaries have planned the necessary funding to bridge the gap.

2) Network-wide S/T training. EURANTES organises 8 network-wide workshops, which focus on the specific research expertise of the participants, thereby stimulating the interdisciplinary contacts. Aligned with these 8 network-wide events, the consortium organises the first-ever, dedicated conference on the Sb supply chain (Belgium) and a Winter School *Multi-criteria assessment of primary and secondary Sb production* (Sweden). Additionally, selected lectures offered at one participant's institution are made available to the broader scientific community via live-streaming "webinars". These network-training activities are obligatory for all ESRs. The Winter School and the Network Conference are also open to external participants.

Network-wide workshops. Network-wide training events allow the ESRs to present their own research results to the other ESRs (programme in Table 6). In addition, the organising participant provides training lectures on its own research or expertise, in most cases together with other participants in order to stimulate the interdisciplinarity of the training courses. Workshops also provide addi-

Evaluation Result

Total score: 97.60%

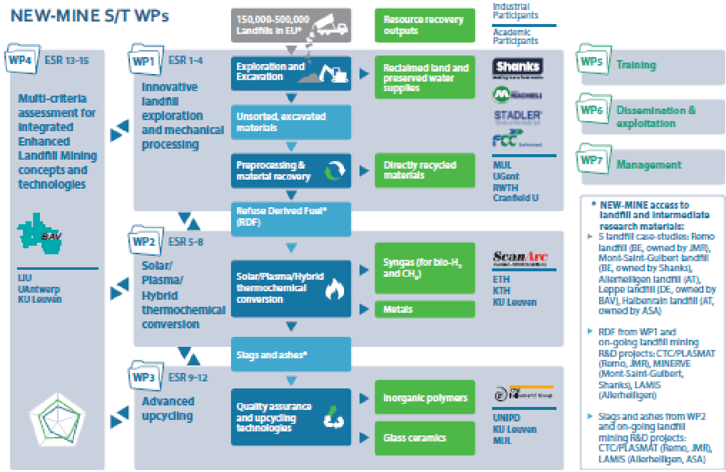

Figure 2. Overview of the NEW-MINE WPs and the value-chain approach

To develop the "raw" geophysical model, test excavations are conducted to obtain more representative samples and a better correlation by implementing the latest research results about quality assurance.[10] This leads to the validation and expansion of the model of landfills as anthropogenic resources by **ESR2**. As such, the excavated materials are subjected to processing to obtain concentrates of the desired raw material. These are the high-heating-value fraction (which can be used as RDF) in the subsequent thermochemical valorisation technologies (WP2), the ferrous and non-ferrous metals, the mineral fraction for the production of building materials, the humic fraction for compost production and the contaminant fraction that has to be sluiced out from the circular economy to a sanitary landfill as the final sink of waste management. Building on the findings from the Austrian LAMIS and Belgian MINERVE ELFM projects, it is clear that two distinct challenges are faced:

1) Excavated MSW from landfills is characterised by the agglomeration and intergrowth of different kinds of waste, which is very challenging with respect to separation technologies compared to recycling from fresh waste.[11] **ESR3** investigates the impact of surface defilements on sensor-based sorting technologies using a modelling approach to increase resource recovery.

2) The state-of-the-art production of RDF leaves about 50% of the mass and about 35% of the heating value unused because co-incineration technologies impose strict requirements on the RDF.[12] However, the advanced thermochemical valorisation technologies in NEW-MINE allow more flexible requirements and higher RDF recovery rates. **ESR4** develops enhanced purification technologies based on wet- rather than dry-processing methods, making it possible to produce RDF from the currently unused fine fraction (which is the Achilles' heel of many LFM projects!).

WP2: Solar/Plasma/Hybrid thermochemical conversion

Figure 2 shows that one of the key fractions from the advanced mechanical processing of excavated landfill waste is the RDF fraction. In *Classic Landfill Mining* scenarios, common in Asia, this RDF fraction is further processed in grate incinerators or co-incinerators (see Text Box 1). In the EU-28 this is less straightforward as the quality requirements for such RDF (especially in the case of co-incineration) are stricter. NEW-MINE, however, envisages totally different thermochemical conversion processes. Based on two separate lines of successful research in Europe, NEW-MINE targets plasma-driven gasification, solar-driven gasification and hybrid combinations, allowing the flexible use of these technologies as a function of the climatic conditions (northern vs. southern Europe). The advantage of these technologies is that they can be tailored to process more variable RDF compositions, while producing higher-value outputs with respect to incineration.

Building upon KU Leuven's and JMR's previous work (i.e., the national projects IWT O&O ELFM & IWT MIP PLASMAT, Remo landfill) **ESR5** and **ESR6** tackle key challenges in the field of the gas-plasma thermochemical conversion of RDF derived from landfills. For this conversion process, gasification is decoupled in two stages: in the first step the RDF is gasified to produce a crude syngas (with or without plasma), while in a second step further "cleaning" of the gas is performed through cracking of the

10 R. Sarc & K.E. Lorber, *Waste Management*, 33 (9) 2013, 1825-1834.
11 T. Wolfsberger, et al., *Waste Management and Research*, doi 10.1177/0734242X15600051
12 A. Bockreis, W. Müller, in: K. Thomé-Kozmiensky, S. Thiel, *Waste Management*, Volume 4 Waste-to-Energy, 2014.

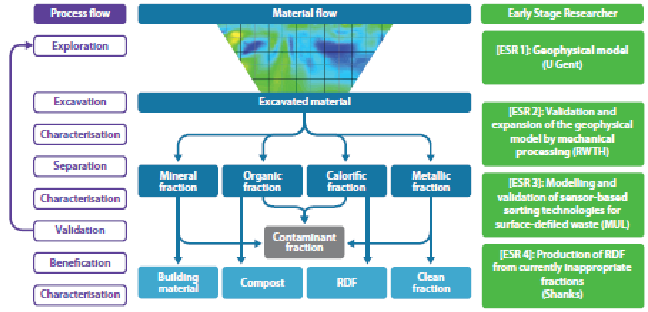

Figure 3. Interrelationships in WP1

remaining organic compounds in the gas, through the use of a high-temperature plasma. The final outputs are a clean syngas (a fuel mixture of mainly H_2 and CO) and a vitrified fraction (which goes to WP3 for further upcycling). **ESR5** focuses on the development of a next-generation steam-plasma-gasification plant for clean and efficient RDF conversion into slag and syngas, verified by experimental tests on the lab and pilot scales. Since the presence of tar greatly impedes the qualitative downstream use of syngas, **ESR6** focuses on the tar-cracking process with plasma, aiming at a thorough understanding of the underlying mechanisms in order to improve and control the operation of the plasma gasification that generates clean syngas.

Building upon ETH Zürich's work (Advanced ERC Grant Aldo Steinfeld – SUNFUELS), **ESR7** and **ESR8** focus on the fundamental and applied aspects of the solar-driven thermochemical conversion of RDF by high-temperature pyrolysis and gasification, including thermodynamic and kinetic analyses, heat- and mass-transfer modelling, and solar-reactor engineering. The goal is to transform the landfill-derived RDF into a clean and energy-rich syngas, which can be subsequently used for the production of high-added-value fuels. The solar-driven thermochemical conversion technology uses concentrated solar radiation as the energy source for high-temperature process heat to effect the highly endothermic reactions of pyrolysis and steam-based gasification. The outputs of the solar process are syngas and an ash fraction (which is also delivered to WP3). **ESR7** focuses on the development of a solar-reactor model, encompassing coupled radiation-convection-conduction heat transfer and chemical kinetics. This model will serve as a tool for the design of the solar reactor and, after an experimental validation, for optimisation and scale-up. **ESR8** focusses on the design, fabrication, and experimental testing of a lab-scale solar-reactor prototype. The experimentation is carried out at ETH's High-Flux Solar Simulator using radiative-transfer characteristics comparable to highly concentrating solar systems. The mass and energy balances are determined during each experimental run for the purpose of determining the performance map (reaction extent, syngas quality, solar-to-fuel energy-conversion efficiency) under various operating conditions. The experimental data are used to validate the heat-transfer model and to demonstrate the technical feasibility of the solar-reactor technology to efficiently convert RDF into clean fuels.

Finally, towards the end of the project, **ESRs 5-8** work together on a hybrid solar/plasma gasification concept based on plasma-driven and solar-driven reactor technologies, which can operate round-the-clock in hybrid mode and thermochemically process RDF into high-quality syngas.

WP3: Advanced upcycling

In order to improve the profitability of any ELFM project the outputs of the thermochemical conversion are further upcycled into products with a high added value. Apart from delivering some metals, the main outputs of the solar/plasma thermochemical conversion are syngas and ashes/slags. Firstly, syngas can be upgraded into either H_2 or CH_4, which has already been achieved by some NEW-MINE participants (incl. JMR) in bilateral projects. This part of the upcycling, which is essential for the overall business case, is therefore not in the scope of the NEW-MINE S/T programme. Secondly, WP2 also generates slags (plasmastone) and ashes. In WP3 these are upcycled into low-carbon building materials.

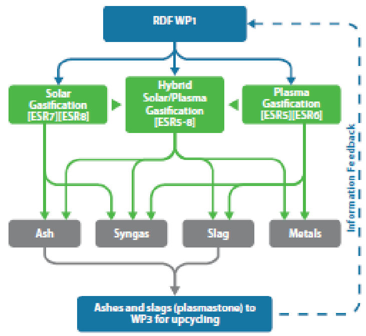

Figure 4. Interrelationships in WP2

Evaluation Result

Total score: 95.40%

Table 6. Typical programme for network-wide workshops.

Day	Board/Meeting	Who?	Organisers
Mon	Am: ESR Presentations from WP1-2a	ESRs + supervisors all ESRs + Representatives industrial Partner Organisations + MST	Host + MST
	Pm: ESR Presentations from WP2b-3-4		Host + MST
Tue	Am: TSC Meeting (WP Presentations by WP Leaders WP1-4)	TSC Members	Host + MST
	Pm: SB (incl. updated WP Presentations by WP Leaders WP1-4 + Presentations WP5-7)	SB Members (Advisory Board: SB1,2,4,6,8)	Host + MST
	(Pm: Recruitment Committee)	RC Members	Host + MST
	(Research/Women Council + Lab visits for ESRs + Guest Lectures by World-Leading experts – topics may be chosen by ESRs)	*ESRs (obligatory)*	*ESRs Host*
	Evening: Official Network-wide Dinner	All (optional)	*ESRs Host*
Wed-Thu-(Fri)	S/T Training, Soft-skill training	ESRs (obligatory) + supervisors (optional)	Host
	Industry/site visits (optional)	ESRs (obligatory) + supervisors (optional)	Host

terms. The research-training programme consists of specific targets for each ESR.[11]

B1.3.2 Non-academic contribution to the supervision

All ESRs recruited by the academic organisations have at least one non-academic secondment, where an industrial supervisor has been appointed (B5 docs). For the ESRs recruited by the industrial Beneficiaries, water-tight arrangements have been made with the relevant academic supervisors and doctoral schools: 1) ESR3 (Metallo), enrolled in Arenberg Doctoral School KU Leuven (main supervisor: B. Blanpain). industrial supervisor: M. Chintinne; 2) ESR4 & ESR6 (Outotec), enrolled in the Aalto U doctoral school (main supervisor: M. Lundström). Industrial supervisor: M. Haapalainen; 3) ESR11 (Kerneos), enrolled in Arenberg Doctoral School KU Leuven (main supervisor: Y. Pontikes). industrial supervisor: H. Fryda. More details of the supervision arrangements are provided in B5 and Table 11.

B1.4 Quality of the proposed interaction between the participating organisations

B1.4.1 Contribution of all participants to the research and training programme

To avoid duplication, we refer to Table 5, where it is clear that the participants take up a central role in the network-wide events (S/T training, soft-skills training, company and site visits, SOCRATES Summer School and Symposium) and the planned secondments.

B1.4.2 Synergies between participants

SOCRATES has been set up with great care to combine complementary expertise, spanning the entire residue-to-metals-and-minerals value chain with 5 companies, involving 2 additional knowledge/technology providers (Outotec, VTT). Likewise, the university partners have complementary expertise in the areas of geology and electrochemistry (ULEIC), plasma-, iono- and solvometallurgy (KU Leuven), hydrometallurgy (Aalto U), theoretical chemistry (UBonn), organic synthesis (KU Leuven), cements and geopolymers (KU Leuven), catalysts (UUtrecht) and systems integration & resource efficiency assessment (TU Freiberg).

B1.4.3 Exposure of recruited researchers to different (research) environments

Each ESR performs at least two secondments, each one lasting for at least 1 month. The timing of the secondments has been agreed. SOCRATES secondments aspire to the Triple-i principle: intersectoral, international and interdisciplinary. Every ESR from the academic institutions is seconded to at least one non-academic participant, where he/she also has a supervisor. Furthermore, the 8 network-wide events offer a multitude of exposure possibilities to different environments (industry and site visits, soft-skills training by non-academics, expert lectures, Summer School etc.).

11 To publish at least 2 papers in international peer-reviewed scientific journals (as first author). To present 1 literature seminar and 1 research seminar. To attend at least 3 international scientific meetings with active participation (oral or poster presentation). To attend at least 10 seminars by guest speakers. To be involved in teaching activities (lecture a course, supervise exercise sessions and a lab course etc.). To report on the progress and the next steps. These requirements are integrated into the doctoral school training, where they are considered as a quality-control instrument for the research training. The training acquired in one doctoral school counts for credits in the doctoral school at which the ESR is enrolled.

B2. Impact

B2.1 Enhancing the career perspectives and employability of researchers and contribution to their skills development

B2.1.1 EU need and transferability

EU need. In contrast with the many, high-quality training and research projects dealing with the supply risk for rare-earth elements, SOCRATES is the first-ever training programme dedicated to other critical metals recovered from EU-based industrial-process residues. As such, SOCRATES develops an independent supply of at least four critical metals: germanium, indium, gallium and antimony. This criticality is a direct result of their economic importance, their supply risk, their medium (Sb, Ga) to poor (In, Ge) substitutability, and their low end-of-life recycling rates. With the forecast average annual demand growth to 2020 (Ga: 8%; In: 5%; Ge: 4%; Sb: 3%)[12], the EU need for a dedicated, intersectoral and interdisciplinary training programme that is capable of unlocking the critical metals in industrial-process residues is evident (see also Priority Area 3 in EC's Action Plan for the Circular Economy). SOCRATES helps to achieve competitive, reliable and sustainable access to these critical metals so that the EU can prevent the strategic downstream manufacturing of critical-metal-based cleantech applications moving to countries like China. As documented by the European Rare Earths Competency Network (ERECON[13]), this has already happened for the production of rare-earth magnets for use in hybrid cars, direct-drive wind turbines or e-bikes.[14] As the objective of SOCRATES is to contribute to the development of a diversified and more sustainable supply chain for non-RE critical metals from industrial-process residues, the move of EU manufacturing (cleantech) to countries like China can be avoided. Moreover, based on its zero-waste systems approach, SOCRATES also helps by providing minerals for developing low-carbon, end-user applications such as supplementary cementitious materials, geopolymers and catalysts.

EU transferability. As SOCRATES is developing cutting-edge chemical and metallurgical solutions based on combinations of pyro-, plasma-, hydro-, bio-, electro-, solvo/ionometallurgy, a significant fraction of the know-how developed by the ESRs is transferrable to the extraction and recovery of critical metals from complex, low-grade, polymetallic *primary* ores. This expertise is also important for the recovery of critical metals other than Ge, In, Ga and Sb from primary ores and secondary residues. ESRs with training in analytical, inorganic and computational chemistry or organic synthesis can be valuable workers in different branches of the chemical industry, ranging from the petrochemical industry to the chemical metallurgy industry. At the same time, the SOCRATES research by **ESRs 11–13** in developing novel end-use applications from the residual mineral fractions (supplementary cementitious materials, geopolymers and catalysts) can be further extended to transforming non-critical-metal-containing residues into the same types of applications (e.g., outputs from thermochemical conversion processes for landfilled waste). Moreover, the integrated assessment techniques that are targeted by **ESR15** are applicable in the broader raw-materials sector.

Considering that 6 SOCRATES participants play a key role in the recently started, flagship EIT Raw Materials, the pan-European impact of SOCRATES can also be guaranteed. These EIT Raw Materials partners are KU Leuven and Umicore (Western Co-location Centre), Boliden (Northern Co-location Centre) and Outotec, Aalto U and VTT (Baltic Co-location Centre). More specifically, one of the 3 Lighthouse Programmes in EIT Raw Materials is "*Lighthouse Programme 1: Extracting value out of residue stocks*". This Lighthouse Programme opens up new material sources for Europe, delivering value to public and private owners of residue stocks and solving environmental issues associated with historical stocks. The impact will also lie in the emergence of a new market, leading to new jobs and the creation of specialised SMEs and joint ventures between larger stakeholders. Since the establishment of the EIT Raw Materials, several KIC Added Value (KAVA) *Network of Infrastructure* Projects linked to SOCRATES have already been approved and funded, e.g. PYROFLEX, SOLVOFLEX, HYDROFLEX and RESIDUFLEX. SOCRATES directly contributes to the *Strategic Implementation Plan* of the EIP Raw Materials, which continuously aligns with the EIT Raw Materials strategy.

B2.1.2 World-class, interdisciplinary training programme

SOCRATES provides the best-possible scientific training by leading experts in the various fields related to the supply chain for critical metals and minerals from industrial-process residues. These experts, including Koen Binnemans, Andy Abbott, Bert Weckhuysen, Barbara Kirchner, Markus Reuter, and many others, are drawn from carefully selected European institutions with long-standing expertise in metallurgy, computational chemistry, catalysts, alternative binders and flow sheet assessments. This guarantees the exposure of the ESRs to state-of-the-art scientific knowledge. SOCRATES combines the challenging task of training excellence with cutting-edge research. The ESRs have to handle their own ambitious scientific research project, while being embedded in an interdisciplinary working field and having access to state-of-the-art equipment and facilities (see B5). The individual working programme foresees at least two extended secondments at a partner lab, with at least one being in a sector different from the primary host. During the network-wide workshops, additional S/T trainings and complementary, soft-skills trainings are given. Entrepreneurship and commercial skills are explicitly stimulated. The ESRs can complement their knowledge in the form of ESRs' workshops, which they organise themselves. With the help from the Technical Steering Committee and the Training WP Group, they can define their own needs in terms of complementary knowledge and invite cutting-edge guest scientists. The trainings acquired within a partner institution are formally recognised by other part-

Figure 9. Interdisciplinarity of SOCRATES research and training, showing the generic skills, soft skills (lead partner indicated), technical skills and scientific disciplines.

12 Report on Critical raw materials for the EU, European Commission, DG Enterprise & Industry, Brussels, 2014.

13 The final ERECON report is available from http://ec.europa.eu/growth/sectors/raw-materials/specific-interest/erecon/index_en.htm.

14 The reason for the latter is that rare earths remain cheaper and more secure for (Western) companies and joint-ventures operating in China.