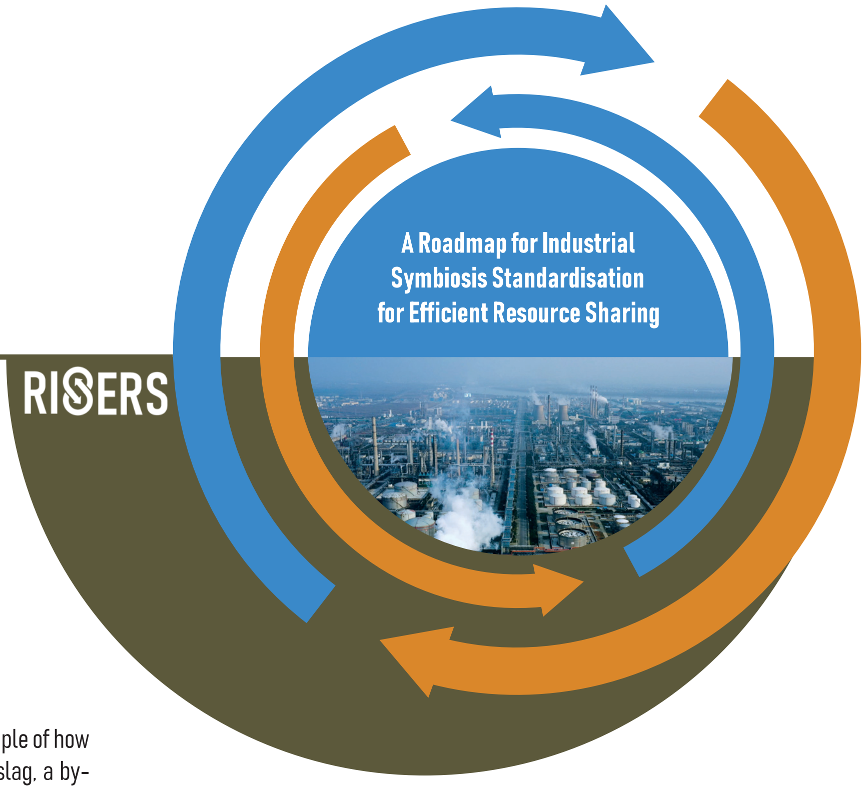
Synergy Fact Sheet



BOF/EAF SLAG

Recover basic oxygen furnace slag and provide silicium, iron, calcium and alumina for clinker raw materials

Introduction

The recycling of basic oxygen furnace slag (BOF slag) is a remarkable example of how industries can work together to turn waste into valuable resources. BOF slag, a by-product of oxygen blast furnace steel production and casting, is rich in useful minerals such as silicon (SiO_2), iron (Fe_2O_3), calcium (CaO) and alumina (Al_2O_3). These properties make it an excellent alternative raw material for cement production, especially in the manufacture of clinker and ground cement. By utilising BOF slag, the steel and cement industries can reduce their dependence on natural resources and adopt more sustainable practises (Demarco et al., 2024).

This process represents an industrial symbiosis in which the steel industry becomes the supplier of the BOF slag and the cement industry uses it to process the raw material. The high calcium content of granulated blast furnace slag helps to meet the lime requirements for clinker production, while its silica, alumina and iron oxides replace other natural raw materials. This collaboration addresses two important challenges: the reduction of waste disposal in the steel sector and the preservation of important raw materials such as limestone and clay in the cement industries (Jexembayeva et al., 2020).

The use of BOF slag in cement production also brings technical and environmental benefits. Modified granulated blast furnace slag, for example, improves grindability, making it easier to process and improving the quality of cement products. In addition, this approach supports environmental goals by reducing carbon dioxide emissions from clinker production and promoting the development of more environmentally friendly building materials (Xiang et al., 2021; Jexembayeva et al., 2020).

The partnership between the steel and cement industries illustrates how waste from one sector can become a resource for another. This industrial synergy not only helps to reduce costs and environmental impact, but is also in line with the principles of a circular economy that creates more sustainable and innovative production cycles. (Aidres, 2023)

Supplying sector(s)		Receiving sector(s)	
Steel	Steel, basic oxygen steelmaking and casting manufacturing	Cement, Various	Cement, raw materials preparation

TECHNICAL FEASIBILITY

Laboratory scale – BOF slag proves to be effective in clinker production and cement grinding, thus confirming its suitability for practical use in the test stage (large laboratory/semi-pilot scale).

Low technical requirements – BOF slag can be seamlessly integrated into existing cement production processes and does not require any significant changes or additional costs

PPP IMPACT – EU wide potential

Profit – Wins in industry
ca. 4.000 M EUR value added. The substitution of BOF slag in cement production offers cost savings by reducing the dependence on traditional raw materials and the need for waste storage, making the process more financially efficient. (source: Scaler)

Planet – Environmental gains
ca. -10 Mt CO_2-eq. (source: Scaler) The integration of BOF slag helps cement manufacturers to reduce greenhouse gas emissions by lowering the amount of clinker required, significantly reducing CO_2 emissions. Yearly ca. 204 Mt of slag produced (Eurosteel, 2018).

People – Wins for society
ca. 40.000 direct jobs. The integration of BOF slag into industrial practice contributes to the creation of direct jobs in sustainable industries and promotes local employment and economic stability. (source: Scaler)

RISERS

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The fact sheet provides a detailed overview of a high-potential and high-impact IS synergy, evaluating its implementation feasibility and sustainability impact. Supported by data from public databases (MAESTRI, SCALER, EPOS, AIDRES, etc.) and literature, it offers a generalised insight into the economic, environmental, and social benefits per synergy.

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Synergy Fact Sheet

A Roadmap for Industrial Symbiosis Standardisation for Efficient Resource Sharing

RISERS

WASTE HEAT

Recover heat from process industry and use for urban heating

Introduction

Industrial waste heat represents a valuable opportunity to improve energy efficiency while reducing environmental impact. This heat, which is normally released unused into the atmosphere, can instead be captured and reused to provide energy to urban areas or other industrial sites. By recovering this heat, industries can reduce their dependence on conventional energy sources, reduce greenhouse gas emissions and contribute to a more sustainable energy system (Moser & Jauschnik, 2023, AIDRES, 2023). One promising application of waste heat is its integration into district heating networks, where it serves as an affordable and reliable source of energy for heating and cooling in cities. Utilising waste heat in this way not only increases energy efficiency, but also helps urban utilities transition to lower-carbon operations, which is in line with international climate goals (Atienza-Márquez, Bruno, & Coronas, 2020). District heating systems are particularly suitable for the integration of low temperature waste heat, as they can utilise different energy sources. By utilising waste heat that would otherwise go unused, these systems can achieve significant energy savings and reduce environmental impact. Thanks to recent technological advances, waste heat can now be transported over longer distances, making it equally interesting for urban and industrial applications (Pakere et al., 2023). The recovery and reuse of waste heat demonstrates the potential for synergies between industrial plants and urban utilities. By converting excess heat into a usable energy resource, industries are taking steps to create innovative, sustainable solutions that benefit both the economy and the environment.

Supplying sector(s)	Receiving sector(s)
Various — Various industries	Urban — Urban utility services, various industries

TECHNICAL FEASIBILITY

Low technical requirements mean that the implementation of waste heat recovery systems is straightforward and requires only minimal changes to existing industrial processes and infrastructures.

Waste heat recovery relies on advanced technologies that enable the efficient capture and reuse of industrial waste heat, providing a viable and effective solution for reducing energy losses and increasing efficiency.

Industrial and urban heat networks enable the seamless integration of waste heat into district heating systems and provide a reliable source of energy for urban and industrial applications via well-developed distribution networks.

PPP IMPACT – EU wide potential

Profit

Wins in industry
Waste heat recovery generates approximately €5.9 billion in added economic value by improving energy efficiency and reducing operational costs across industries. (source: Scaler Synergy 91, EPOS CW03, Cervo et al., 2019)

Planet

Environmental gains
The environmental benefits are relatively low, reflecting modest reductions in emissions and resource use. (source: EPOS CW03, Cervo et al, 2019)

People

Wins for society
The sector creates around 60,000 direct jobs, contributing significantly to local employment and economic development. (source: Scaler Synergy 91)

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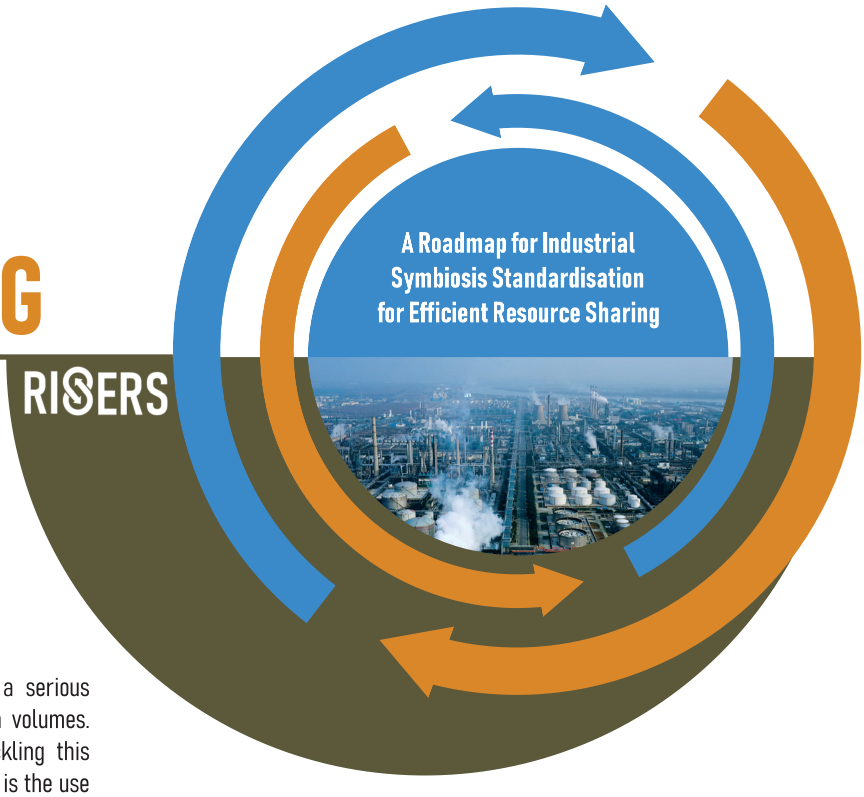

PLASTIC PACKAGING

Use plastic waste as alternative resource/fuel in industrial processes like cement kilns or recycle plastics as a substrate for new materials production

Introduction

Plastic waste from packaging, especially single-use plastics, poses a serious environmental problem due to its durability and increasing production volumes. Developing effective recycling and reuse strategies is crucial to tackling this challenge and promoting sustainable practices. One innovative approach is the use of plastic waste in industrial applications, such as in the minerals sector, where it can serve as a valuable alternative material (Torkelis, Dvarionienė, & Denafas, 2024). Modern recycling techniques, including chemical processes such as gasification and incineration, offer efficient ways to convert lightweight plastic packaging waste into useful materials. These methods not only reduce dependence on landfill disposal, but also offer environmental and economic benefits through the recovery of materials that can be reused in industrial production (Voss, Lee, & Fröhling, 2022, AIDRES, 2023). Material flow analysis (MFA) is an important tool for designing sustainable waste management systems. By mapping how plastic waste moves through and accumulates in the system, MFA helps industries such as the minerals sector to efficiently incorporate these waste streams into their processes (Choi, Hwang, Yoon, Jeon, & Rhee, 2024). The use of plastic packaging waste in sectors such as the minerals industry supports waste reduction while contributing to the principles of a circular economy. This approach transforms waste into a resource and offers practical and sustainable solutions to the global plastic waste challenge.

Gradual replacement of fossil-based plastics by recycled or sustainably sourced feedstock is aimed to reach 65% by 2050 (Plastics Europe, 2024)

Supplying sector(s)

Various — Various

Receiving sector(s)

Various, Cement — Cement, Various

TECHNICAL FEASIBILITY

The industrial-scale recycling of plastic packaging waste is adaptable to large-scale operations, supporting the high-volume processing required for industrial applications

High technical requirements: Advanced technologies, such as chemical recycling including gasification and incineration-based processes are necessary to efficiently convert plastic waste into usable materials for industrial sectors, such as mineral processing

PPP IMPACT – EU wide potential

Profit

Wins in industry
The reuse of plastic packaging waste brings economic benefits as fewer new raw materials are required and the efficiency of industrial processes is improved. The 16.1 Mt of plastic packaging waste was produced in 2021, of which 6.56 Mt was recycled (Eurostat database).

Planet

Environmental gains
Recycling plastic waste helps reduce the amount of material sent to landfill, reducing pollution and greenhouse gas emissions. According to the EU Plastic Packaging Waste (PPW) regulation, a 55% recycling target is set for 2030, with an ambition to achieve approximately 65% recycled content in plastic packaging by 2040.

People

Wins for society
Modern recycling technologies create new jobs, boost local economies and contribute to wider sustainability goals.

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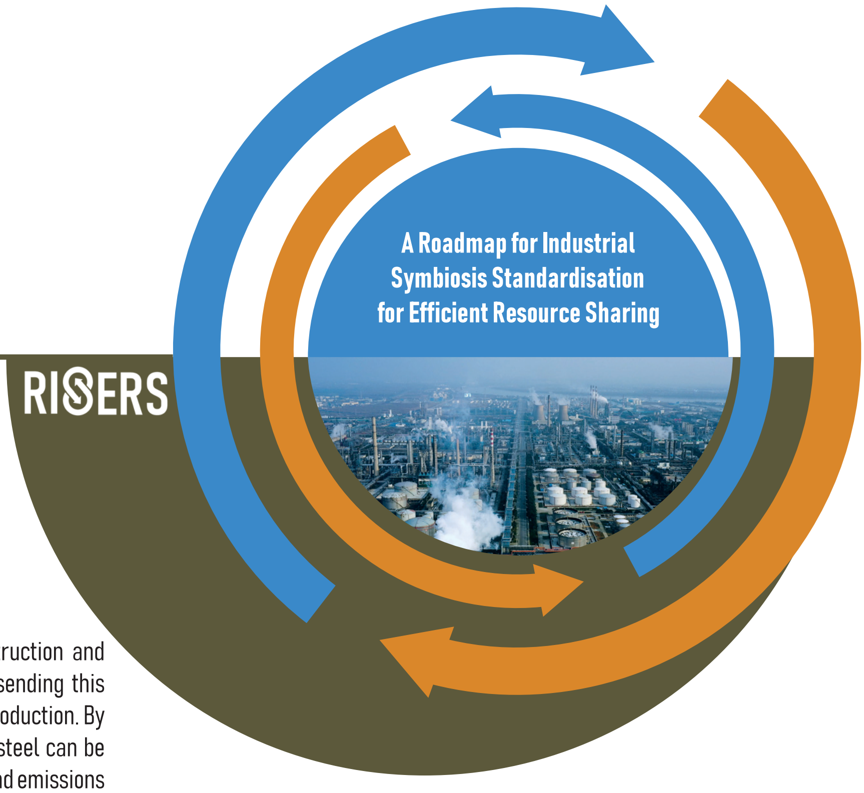

WASTE STEEL

Recovery of waste steel for recycling (secondary steel making)

Introduction

Every year, millions of tonnes of steel waste are generated from construction and infrastructure projects as well as from end-of-life vehicles. Instead of sending this waste to landfill, it can be recycled and used as a raw material for steel production. By using modern technologies such as electric arc furnaces (EAF), recycled steel can be processed more efficiently. This not only reduces the energy consumption and emissions compared to traditional methods based on the extraction of iron ore but also allows for the integration of innovative valorisation opportunities. For example, waste steel by-products can be repurposed for use in alternative materials such as construction aggregates or in the production of advanced composites for various industrial applications (Pauliuk, Wang, & Müller, 2013).

Recycling steel is not only good for the environment, it is also a big win for the economy. It fits perfectly with the European Union's goals such as the European Green Deal, which emphasises the need to reduce waste and move towards a circular economy (Metabolic, 2021). Furthermore, industrial symbiosis, as demonstrated in the steel industry, shows how cross-sector collaboration can unleash innovation and efficiency gains (Lombardi & Laybourn, 2012, AIDRES, 2023).

By closing the loop on materials such as steel, industries can reduce their dependence on raw materials, ensure a more secure supply chain and improve their resilience to economic and environmental challenges.

Beyond the numbers and the politics, this approach has other benefits for society. It encourages innovation in recycling technologies, creates skilled jobs and helps companies to remain competitive on a global scale. Additionally, the valorisation of steel industry by-products can extend into unconventional areas, such as the development of biodegradable packaging materials or nutrient-rich soil amendments for agricultural use, demonstrating the versatility of industrial symbiosis. With industrial symbiosis, the steel industry is proving that sustainable practises can go hand in hand with economic growth, paving the way for a greener future.

In short, recycling steel waste is more than just a smart use of resources — it's a multi-faceted strategy that supports circular economy goals, drives innovation across industries, and contributes to a cleaner, more sustainable industrial economy. It's a win-win situation for businesses, the planet, and future generations.

Supplying sector(s)	Receiving sector(s)
Urban, Various: Urban, Various	Steel: Iron and steel production

TECHNICAL FEASIBILITY

Industrial scale – the processing of steel waste is tailored to industrial conditions so that large quantities of recyclable materials can be processed

Low technical requirements – the implementation of processes for recycling steel waste requires relatively little technological effort compared to alternatives based on new raw materials.

Electric Arc Furnace (EAF) – technologies enable a significant reduction in greenhouse gas emissions and an improvement in energy efficiency in secondary steel production.

PPP IMPACT – EU wide potential

Profit

Wins in industry- ca. 79 Mt of steel scrap (EU, 2022)
Steel recycling makes a significant contribution to industrial efficiency. In 2022, around 79 million tonnes of steel scrap will be recycled in the EU, which corresponds to 56% of total crude steel production (European Recycling Industries' Confederation)

Planet

Environmental gains resource efficiency ca. 160 Mt avoided CO_2-eq
The recycling of 94 million tonnes of steel scrap in 2018 avoided an estimated 157 million tonnes of CO_2-equivalent emissions in the EU (European Recycling Industries' Confederation.)

People

Wins for society environmental and health improvement skilled employment
The European steel industry directly secures around 306,000 skilled jobs and indirectly millions more jobs, while improving public health through lower emissions and pollution (EUROFER, 2023).

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ENERGY DATA

Optimise electricity sourcing and provide flexibility via demand-response

Introduction

Industrial clusters rely on innovative approaches to improve their energy management with a strong focus on flexiblility mechanisms, above all demand response mechanisms. With the increasing spread of renewable energies, **their inherent fluctuations pose a challenge for the coordination of supply and demand, requiring flexible solutions across the system. Advanced systems, including virtual power plants (VPPs)**, help harmonise the industry's energy use with the real-time dynamics of the grid. **Flexibility mechanisms, such as sophisticated negotiation techniques, ensure that the industry can respond effectively to demand response events without disrupting operations.** Studies using greenhouse simulations, for example, show the effectiveness of such coordination in meeting grid demand (Clausen et al., 2016).

Managing the variability of renewable energy sources such as wind and solar is essential for archieving flexibility in industrial clusters. Advanced techniques, such as statistical sampling in combination with clustering, categorise energy loads into primary, secondary and tertiary groups, each with specific characteristics. Supplying sectors such as manufacturing, transport and heavy industry provide flexible energy resources, while receiving sectors such as the energy sector grid operators utilise these resources to balance and optimise grid performance. Combined with emissions trading schemes and integrated solutions for hydrogen and heat, this model increases economic outcomes and operational efficiency. These approaches not only rationalise the interactions between energy producers and consumers, but also reduce the costs and uncertainties of energy supply (Cao et al., 2024). With the increasing importance of renewable and decentralised energy resources, complex problems arise in terms of grid control, communication, and market dynamics. Flexible energy systems address these challenges by connecting decentralised generators, storage solutions, and electric vehicles into unified networks capable of delivering reliable energy and ancillary services. The supplying sectors contribute decentralised resources, such as renewable generators and energy storage, while the receiving sectors benefit from stable energy flows and ancillary services. Innovations such as the incorporation of blockchain technology further enhance performance by improving coordination and management across system levels. These advances enable flexibility solutions to effectively address market challenges while optimising resource allocation (Roozbehani et al., 2022).

In addition to efficiency gains, the environmental benefits of **flexibility strategies, including demand response**, are significant. By utilising renewable energy during production peaks and storing surplus energy for later use, these systems significantly reduce greenhouse gas emissions while promoting a circular economy. In addition, they enable smaller companies within industrial clusters to access energy markets by utilising shared infrastructure to reduce costs and increase resilience. The interaction between supplying and receiving sectors promotes industrial symbiosis, which brings mutual benefits to participants and strengthens the overall energy framework (Cao et al., 2024; Clausen et al., 2016, Baetens, 2022, Trilate, 2021). To summarise, the integration of demand-driven flexibility in industrial clusters **is a transformative strategy. These solutions not only promote industrial efficiency and sustainability but also contribute to the development of a more robust and environmentally friendly energy framework**.

Supplying sector(s)	Receiving sector(s)
Various: Various sectors	Energy: Energy sector VPP operator

TECHNICAL FEASIBILITY

- **Industrial scale:** Virtual Power Plants (VPPs) are designed for large-scale implementation, enabling industry to efficiently manage large amounts of energy across multiple sites and clusters. This adaptability makes VPPs suitable for energy-intensive applications.
- **Moderate technical requirements:** VPPs utilise accessible and scalable technologies that simplify integration into existing systems while being cost-effective.

PPP IMPACT – EU wide potential

Profit

Wins in industry
reduction of power instability (smartEN, 2030)
ca. 5-10% electricity cost savings
ca. 11-29 bn EUR in grid investments
ca. 71 bn EUR saved at consumer level
ca. 2.7 bn EUR avoided peak generation

- **Optimising power consumption:** By using advanced demand-response strategies, VPPs enable the industry to match energy consumption to supply, improve overall efficiency and reduce waste.
- **Securing power supply:** Pooling decentralised energy resources ensures a reliable and stable power supply, which is essential for uninterrupted industrial operations.
- **Integrating sites and clusters:** VPPs connect industrial sites and clusters into a cohesive energy management network, improving coordination and resource allocation.
- **Enabling renewable energy:** By supporting the integration of renewable energy sources, VPPs reduce dependence on fossil fuels and pave the way for cleaner and more sustainable energy systems.

Planet

Environmental gains

Flexible power plants are key to supporting the integration of renewables and driving the transition to cleaner energy systems (smartEN, 2030). By reducing overall energy demand by 10-45% and preventing the curtailment of 16 TWh of renewable energy, these systems help to reduce greenhouse gas emissions by around 38 million tonnes of CO_2 equivalent.

People

Wins for society

VPPs contribute to stronger and safer electricity grids while reducing associated costs. Beyond the economic benefits, they create new jobs and promote skills development, support local economies and advance EU-wide sustainability goals

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Synergy Fact Sheet

BIOMASS

Production of alternate fuels or the use of biomass as a feedstock for the production of bio-based materials

Introduction

Using the Fischer-Tropsch (FT) process, a variety of feedstocks, including biomass, can be converted into customised fuel products and other valuable outputs. The process is a technology that converts synthesis gas – a mixture of carbon monoxide and hydrogen – into liquid fuels makes it an excellent option for integrating renewable resources into the energy system, helping to reduce dependence on fossil fuels and decrease greenhouse gas emissions. In addition to producing liquid fuels, the FT process offers alternative valorisation opportunities, such as the production of waxes, lubricants, and chemicals that are widely used in industrial applications, as well as potential applications in the food industry. The European Union has recognised the importance of FT-derived biofuels for the sustainability and security of energy supply, especially with regard to the transition to a low-carbon future (Hu et al., 2012; European Academies Science Advisory Council, 2012; Singh et al., 2024, AIDRES, 2023). Sustainable fuels, biodegradable materials and feed- or food products can also be derived from biological processes, using microorganisms, including bacteria, fungi and yeast to convert biomass into materials, chemicals, pharmaceutics and/or energy streams (biogas, hydrogen, heat, electricity). This biobased economy gains an increasing importance in the development of a sustainable and circular bioeconomy. The utilisation of biomass preferentially happens by clustering parallel exploitation of side-flows, reducing and/or recovering waste and residues, thereby boosting resource efficiency as well as recycling and circularity in so-called 'bio-refineries'.

Supplying sector(s)

Urban | Various — Urban entity, Food industry — Wood processing, Agriculture

Receiving sector(s)

Refining | Various — Refineries, Various

TECHNICAL FEASIBILITY

Industrial scale - The FT process in combination with gasification of biomass is well suited for industrial scale applications. Existing plants have shown that they are capable of processing large quantities of raw materials, making the technology suitable for wide application.

Low technical requirements - Utilising the infrastructure from fossil FT production greatly simplifies the implementation of biomass-based processes. Gasification and synthesis technologies are continuously being improved, which reduces the technical hurdles.

Fischer-Tropsch from gasification + catalytic synthesis:

- **Solid industrial waste:** Residues from agriculture and forestry can be efficiently converted into synthesis gas, which is the main input for FT synthesis.
- **Agricultural residues (straw-like):** Straw and similar by-products are a widely available and sustainable feedstock for biofuel production.
- **Agricultural woody and forestry residues:** Woody materials that are rich in carbon are ideal for the FT process and are in line with circular economy principles.

PPP IMPACT – EU wide potential

Profit

Wins in industry

FT biofuels could deliver 130–200 Mtoe by 2050, strengthening Europe's energy security and diversifying its energy mix (Concawe, 2022). As part of the €725 billion EU bioeconomy (BIC, 2021), they support the shift toward a more sustainable energy system.

Planet

Environmental gains

Each Mtoe of FT biofuel can reduce greenhouse gas emissions by around 2.8 kilotonnes (kt) of CO_2 equivalent. Scaling up production to its potential by 2050 could result in millions of tonnes of avoided emissions and play a crucial role in mitigating climate change (Concawe,2022; ETIP Bioenergy 2022)

- **Lignocellulosic (woody) crops:** Specialised energy crops such as short rotation coppice provide a stable and renewable biomass source for advanced biofuels.

People

Wins for society

The FT process reduces air pollution, improving public health, and supports economic growth through skilled jobs (EUROFER, 2023). As part of the EU bioeconomy, which employed 3.3 million people in 2021 (BIC, 2021), it strengthens rural development and local economic resilience.

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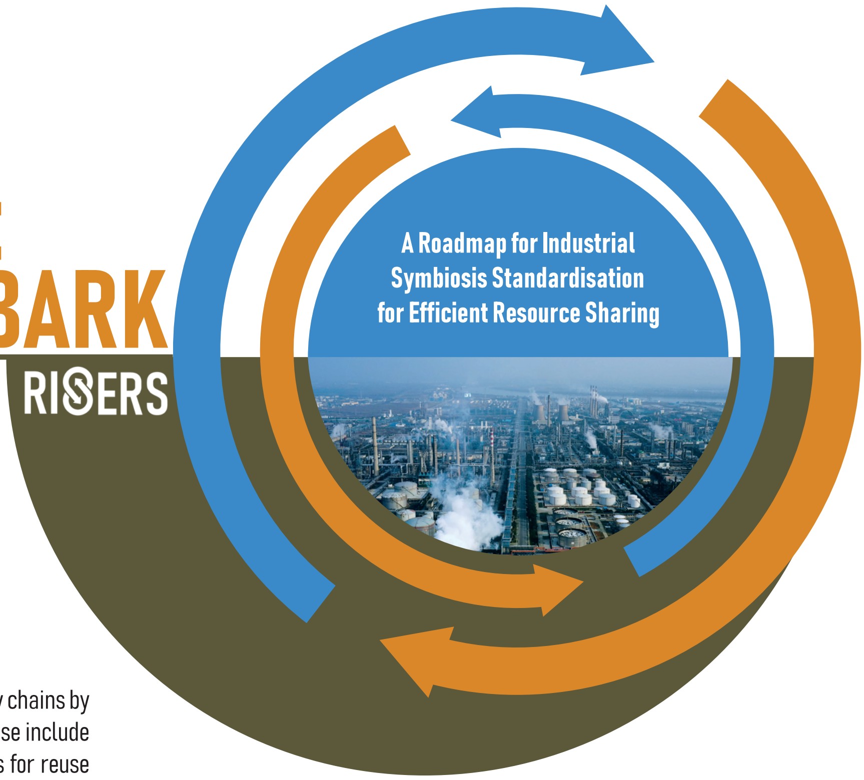
Synergy Fact Sheet

BIOMASS RESIDUES: WASTE WOOD AND BARK

Recover waste wood from pulp and paper sector, combustion plants



Introduction

The pulp and paper sector makes an important contribution to global supply chains by providing essential materials while generating a range of by-products. These include wood waste and associated residues, which offer significant opportunities for reuse beyond traditional disposal methods. This waste, which is mainly generated in kraft pulp mills, is produced during processes such as combustion in recovery boilers, biomass boilers and lime kilns. These processes produce biogenic CO_2, which provides an opportunity for carbon capture and utilisation. By using carbon capture and utilisation (CCU) or storage (CCS) technologies, the industry can reduce emissions and develop innovative bio-based materials, including precipitated calcium carbonate and lignin derivatives (Kuparinen et al., 2019). In addition, wood waste from the pulp and paper sector can serve as a renewable fuel source for combustion plants, contributing to energy generation while reducing reliance on fossil fuels.

In addition to biomass residues, large quantities of inorganic by-products such as green liquor, slaked sand, lime sludge and boiler fly ash are also produced. In the past, these materials were disposed of in landfill sites. However, advances in industrial processes and the increasing adoption of circular economy practises have created opportunities for their reuse. These by-products are now being utilised in diverse applications, including the development of alternative materials such as fillers and binders for construction, nutrient supplements for agriculture, and additives for environmental remediation. Furthermore, emerging research suggests potential applications of certain residues in the food industry, such as using lignin derivatives in packaging materials or as feed additives. These by-products are now being reused for applications in construction, agriculture and environmental remediation, contributing to sustainability goals and reducing reliance on landfills (Quina & Pinheiro, 2020).

Rotary lime kilns, which are an essential part of the Kraft process, play a key role in converting lime slurry into reusable lime within the production cycle. Modelling using computational fluid dynamics (CFD) has provided valuable insights into the mechanisms of heat transfer and calcination in these kilns. This knowledge enables the industry to optimise the efficiency of the kilns, reduce energy consumption and ensure consistent lime quality. Additionally, these kilns contribute to industrial symbiosis by utilising waste wood as an alternative fuel. By burning waste wood instead of conventional fossil fuels, the pulp and paper industry reduces its carbon footprint while transforming waste streams into valuable energy resources (AIDRES, 2023). This approach not only supports sustainability goals but also enhances economic efficiency by reducing reliance on non-renewable energy sources. By integrating cutting-edge technologies and prioritising sustainable practises, the pulp and paper industry is well positioned to transform waste streams into valuable assets and promote both environmental sustainability and economic growth (Ryan et al., 2022).

Supplying sector(s)			Receiving sector(s)	
Pulp & Paper	Various	Combustion plant, coal combustion	Energy	Energy

TECHNICAL FEASIBILITY

Industrial scale: The recovery and reuse of wood waste can be effectively scaled up and enables the efficient processing of large quantities to meet industrial energy needs.

Low technical requirements: Setting up waste wood recovery systems is simple and requires limited technical expertise and resources, making it viable for a wide range of facilities.

Collecting wood waste for incineration: Efficient collection and processing of wood waste ensures its consistent use as a fuel source in incineration plants, supporting reliable energy production.

PPP IMPACT – EU wide potential

Profit

Wins in industry

The utilisation of wood waste generates significant economic value, amounting to around EUR 130 million across the EU. For example, Case 82 in the Scaler project, demonstrates how industry sucessully recover wood wate transforming it into energy and reducing operational costs. This initiative not only increases industrial efficiency, but also strengthens the region's economic framework by promoting sustainable resource management.

Dissolved gas flotation (DGF): Advanced techniques such as DGF improve the separation of impurities from waste wood, improve fuel quality and reduce emissions during combustion.

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Planet

Environmental gains

The reuse of wood waste plays a crucial role in reducing environmental impact, saving approximately 840,000 tonnes of CO_2 annually. Case 87 in the SCALER project demonstrates how waste wood recovery significantly contributes to lowering CO_2 emissions while aligning with the EU's climate targets. This example supports the transition to greener industrial practices and highlights the environmental potential of wood waste utilisation.

People

Wins for society

Waste wood recovery initiatives create around 1,300 direct jobs, boost local economies, and foster skill development in sustainable industries. As illustrated by Case 82 in the SCALER project, such initiatives strengthen industrial symbiosis, enhance community resilience, and encourage a broader shift toward environmentally conscious practices.

RISERS

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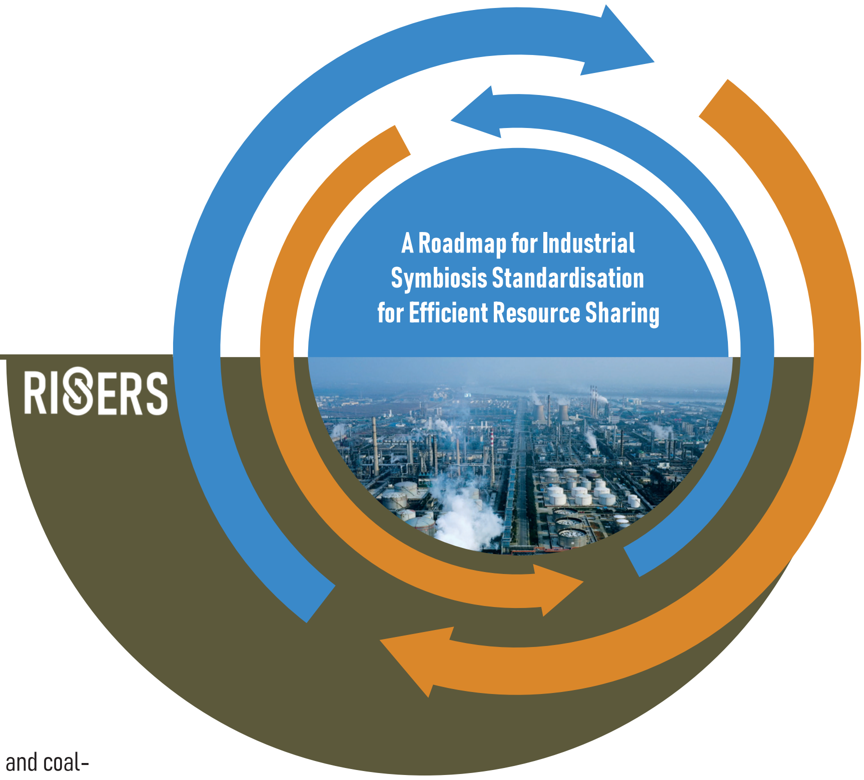
Synergy Fact Sheet

REFRACTORY MATERIALS

Recover fly ash and extract mineral products (silicium, calcium, aluminium) to provide brick and roof tiles manufacturing



Introduction

The recovery of fly ash from industrial processes such as steel production and coal-fired power generation offers a remarkable opportunity to convert waste into valuable materials. Classified as hazardous, fly ash is rich in minerals such as silica, alumina and calcium, which can be extracted and reused for various applications. By utilising advanced recovery technologies, these minerals can be used to manufacture products such as bricks, roof tiles and glass ceramics, reducing dependence on virgin resources and contributing to a circular economy (Yadav & Fulekar, 2020, AIDRES, 2023).

Research has shown the potential of integrating fly ash with waste glass to produce glass-ceramic composites. This innovative approach not only enhances the mechanical properties of the materials, but also offers a sustainable alternative to conventional production methods (Mangutova et al., 2004, Triana D., 2023).

Fly ash has proven to be a useful additive in the production of bricks and tiles. Studies have shown that fly ash can improve the strength and durability of fired bricks, making it a viable option for large-scale production. By refining sintering processes and optimising clay-ash mixtures, manufacturers can produce high quality products while addressing the environmental issues associated with fly ash disposal (Koukouzas et al., 2011 , Triana D., 2023).

These advances are in line with global sustainability goals and offer economic, environmental and social benefits. Through innovative collaboration, the industry can transform fly ash from a waste product to a cornerstone of sustainable development.

Supplying sector(s)

Steel

Steel, electric arc furnace steelmaking and cast manufacturing

Receiving sector(s)

Glass | **Construction** | **Ceramics**

Glass, container glass manufacturing without abatement system

TECHNICAL FEASIBILITY

Under development: The recycling of fly ash for mineral recovery is an evolving field where advances in methods and scalability are constantly being made. Researchers are actively working to refine the processes and ensure their feasibility for widespread application.

High technical requirements: The extraction of valuable minerals such as silicon, calcium and aluminium relies on highly sophisticated methods, including hydrometallurgical extraction and solvent extraction/electrowinning. These advanced techniques require precision, specialised equipment and expertise to achieve optimum efficiency.

PPP IMPACT – EU wide potential

Profit

Wins in industry
Recycling fly ash contributes around €680 million to the economy by reducing dependence on virgin raw materials and improving waste management systems. This creates opportunities for industrial growth and opens up new markets for sustainable products. (SCALER Project)

Planet

Environmental gains
The reuse of fly ash significantly reduces its environmental footprint by avoiding an estimated equivalent of 340,000 tonnes of CO_2 annually. This is in line with global climate targets as landfill waste is minimised and natural resources are conserved. (SCALER Project)

People

Wins for society
These processes are expected to create around 7,000 direct jobs, promote skills development and boost the local economy. By promoting sustainable practises, this initiative promotes social wellbeing and supports long-term economic resilience. (SCALER Project)

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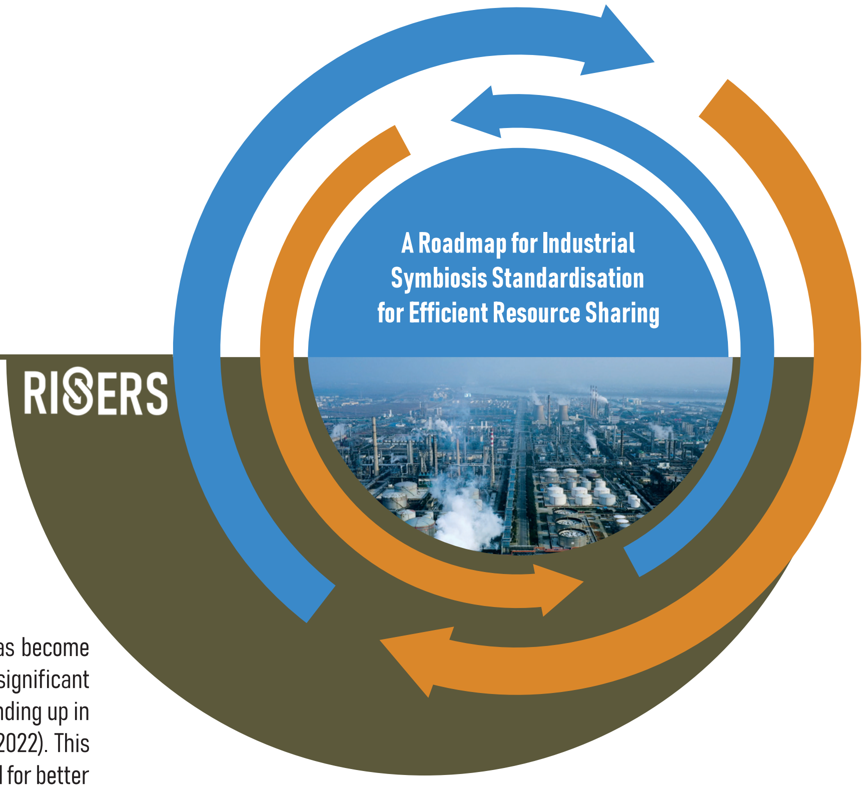

TEXTILES

Produce secondary raw materials from unwearable textile waste

Introduction

Due to its rapid growth and the fast fashion trend, the textile industry has become one of the main causes of environmental problems. Textiles make up a significant portion of municipal solid waste, with an estimated 75% of textile waste ending up in landfills and only 25% being recycled or reused (Juanga-Labayen et al., 2022). This heavy reliance on landfill is unsustainable and emphasises the urgent need for better recycling and reuse strategies to reduce textile waste. Innovative solutions such as anaerobic digestion, fibre regeneration and thermal recycling, together with policy measures such as extended producer responsibility (EPR), lay the foundation for a circular economy in the textile sector.

Modern recycling technologies are now addressing the challenges posed by blended fabrics, which often combine materials such as cotton, polyester and elastane. While mechanical recycling methods have reached their limits in separating these blends, advanced chemical techniques such as dissolution and hydrolysis have shown great promise. These processes enable the recovery of high-quality fibres that can be reintegrated into production to promote sustainable practises and reduce the environmental impact of textile manufacturing (Stubbe et al., 2024).

As consumers and governments increasingly demand more sustainable textile products, the industry is being pushed to move from traditional linear models to circular models. Key innovations such as automated sorting technologies and virtual platforms that encourage collaboration between stakeholders are helping to streamline recycling efforts. With these advances, the textile industry is taking meaningful steps to reduce its environmental footprint and strive for a more sustainable future (Choudhury et al., 2024).

Adopting these innovative practises and technologies gives the textile sector the opportunity to take a leading role in the circular economy. By fostering collaboration and innovation, textile fibre recycling not only contributes to economic growth, but also plays a crucial role in achieving global sustainability goals

Supplying sector(s)	Receiving sector(s)
Textiles: Textiles	Various: Various

TECHNICAL FEASIBILITY

Industrial scale: Large-scale recycling of textile fibres is feasible to effectively manage the significant volume of waste generated by the industry. By operating on this scale, recycling plants can process large quantities of material, ensuring efficiency and broad impact.

High technical requirements: Advanced recycling systems for textiles rely on sophisticated methods, especially when it comes to blended fabrics. Technologies such as chemical dissolution, hydrolysis and enzymatic treatments require specialist expertise and equipment to ensure the successful recovery of fibres.

PPP IMPACT – EU wide potential

Profit

Wins in industry
Recycling textile fibres reduces dependence on virgin raw materials and enhances waste management systems, creating significant economic value. By introducing circular practises, companies strengthen their supply chains, reduce production costs and open up new opportunities in the market for recycled textiles.
According to McKinsey (2022), fibre-to-fibre recycling could recover approximately 18-26% of gross textile waste by 2030, translating into a projected profit of €1.5-2.2 billion annually. This demonstrates the significant economic potential of scaling recycling technologies within the textile industry.

Planet

Environmental gains
The introduction of advanced recycling technologies minimises the environmental footprint of the textile industry. Reducing landfill waste and lowering greenhouse gas emissions are important outcomes, as well as reducing resource extraction and energy consumption, which are in line with global climate goals. For

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example, fibre-to-fibre recycling could avoid approximately 15-35 tonnes of CO2 equivalent emissions per tonne of textile product (ETC, 2019), amounting to a reduction of around 4 million tonnes of CO2 equivalent by 2030 (McKinsey, 2022). These measures significantly support international climate objectives.

People

Wins for society

Recycling programmes contribute to job creation, particularly in the areas of sorting, processing and technological innovation. These initiatives also promote skills development and strengthen local economies, bringing far-reaching societal benefits while driving sustainable practises. As highlighted by McKinsey (2022), the scaling of textile recycling initiatives could create approximately 15,000 skilled jobs by 2030, fostering expertise in sustainable industries and contributing to local economic resilience.

RISERS

About this factsheet

This fact sheet is based on the findings of the RISERS project. Led by Ghent University with the support of project partners, the study involved a systematic assessment of 600+ industrial symbiosis (IS) cases across urban-industrial and cross-sectoral clusters in Europe. These cases formed the basis for the mapping of over 300 MES (Materials, Energies, Services) streams, categorised by output (source) and input (sink) sectors.

The fact sheet provides a detailed overview of a high-potential and high-impact IS synergy, evaluating its implementation feasibility and sustainability impact. Supported by data from public databases (MAESTRI, SCALER, EPOS, AIDRES, etc.) and literature, it offers a generalised insight into the economic, environmental, and social benefits per synergy.

Factsheets authors:

Lieven Demolder, Greet van Eetvelde (Ghent University)
Izabela Ratman-Kłosińska, Grzegorz Gałko, Mateusz Korcz (IETU)

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For more information and access to the full reports, please visit https://risers-project.eu

About the RISERS project

RISERS is a Horizon Europe project aimed at developing an Industrial Symbiosis Standardisation Roadmap supporting the uptake of high impact synergies and resources considering:

- identification of the needs, gaps and opportunities,
- revision of current standards and standardisation efforts relevant for CE and the priority synergies and resources,
- initiating the process of new standards development (especially for newer technologies and pilot-scale synergies).

The RISERS project was launched in January 2024 with a duration of 3 years.

For more information visit: https://risers-project.eu

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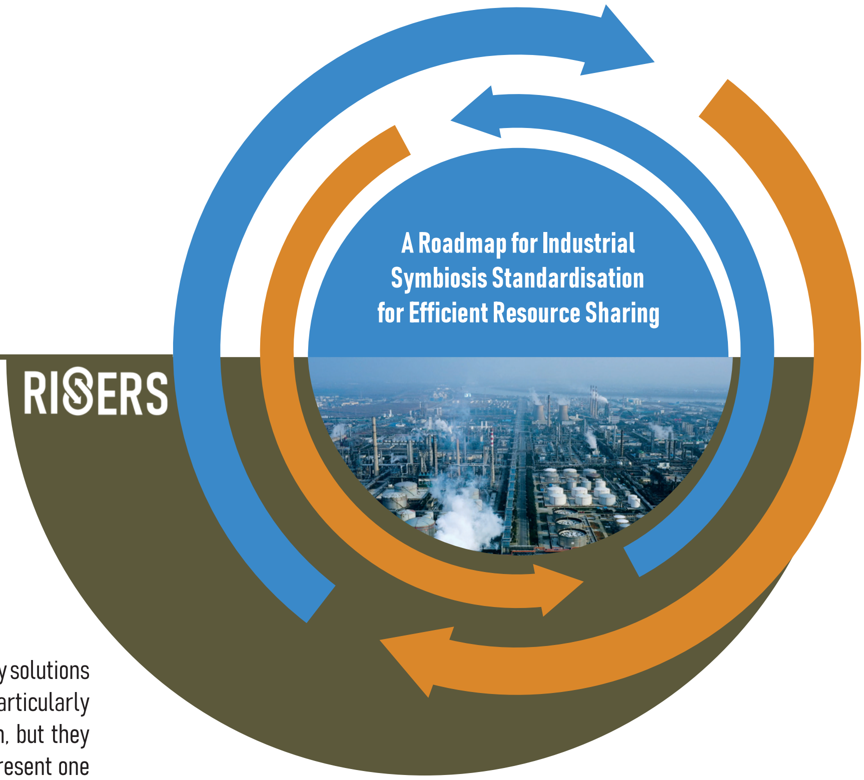
Synergy Fact Sheet



EV-BATTERIES

Recover Lithium and other rare earth elements, reuse for energy storage

Introduction

The shift towards electrified transport and the increasing use of clean energy solutions is changing the global energy landscape. Electric vehicle batteries, particularly lithium-ion batteries, play a crucial role in the broader energy transition, but they are not the sole or central element driving this change. Instead, they represent one of many complementary technologies contributing to greater sustainability. As the market for electric vehicles continues to grow, efficient life cycle management for these batteries is becoming increasingly important. Reuse and recycling are essential strategies to reduce the environmental impact of EV batteries while ensuring the sustainable use of critical resources such as lithium and rare earths (Jose et al., 2024). Rare earth elements (REEs), which are an essential component of energy conversion technologies such as EV batteries and wind turbines, are both scarce and difficult to extract and recycle. With demand growing at 10% annually, recycling rare earths is becoming an important addition to traditional mining practises. However, current recycling rates are extremely low — only 2% — highlighting the urgent need for advanced technologies to improve separation and processing efficiency (Patil et al., 2022). By addressing these challenges, the industry can promote a circular economy, reduce reliance on newly mined materials and minimise the environmental damage associated with mining and disposal.

Supplying sector(s)	Receiving sector(s)
Transport	Energy, Minerals

TECHNICAL FEASIBILITY

Industrial scale: The reuse and recycling of electric car batteries can be extended to a significant amount of end-of-life devices. This scalability ensures that the growing demand for sustainable resource management in the transport and energy sectors can be effectively met.

High technical requirements: The recovery of valuable materials such as lithium and rare earths requires sophisticated technologies. Processes such as hydrometallurgical extraction and solvent-based separation require advanced equipment, precision and technical expertise to achieve high recovery rates while protecting the environment.

PPP IMPACT – EU wide potential

Profit – Wins in industry

The reuse and recycling of electric car batteries has significant economic benefits, generating around EUR 2 billion annually for the EU economy. These practises reduce material costs, improve supply chain resilience and create new market opportunities in energy storage and materials (Drabik et al., 2018)

Planet – Environmental gains

The recycling and reuse of EV batteries offer significant environmental benefits, avoiding an estimated 1.5 million tonnes of CO_2 equivalent per year. By 2030, approximately 130 GWh of lithium-ion batteries are expected to reach the end of their life, requiring a recycling capacity of 700 kt to manage this volume effectively. This capacity is projected to grow further, with an estimated 400 GWh of batteries requiring recycling by 2040 (ADlittle, 2022). This approach aligns with EU climate goals as it conserves natural resources, reduces landfill waste, and mitigates the environmental impact of mining (Drabik et al., 2018).

People – Wins for society

The expansion of electric car battery recycling initiatives is expected to create over 20,000 direct jobs across Europe. These efforts support skills development, encourage innovation and strengthen local economies, contributing to a more sustainable and equitable future for all (Drabik et al., 2018)

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