The role of slags and other by-products within circular economy in the steel industry

5.–6. MARCH 2025

ESTEP Focus Group Circular Economy & FEhS-Institute

- Assessing the progress of the impact of Industrial Symbiosis on the steel sector in recent initiatives based on the Symbio-Steel project: workshop
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ESTEP
European Steel Technology Platform

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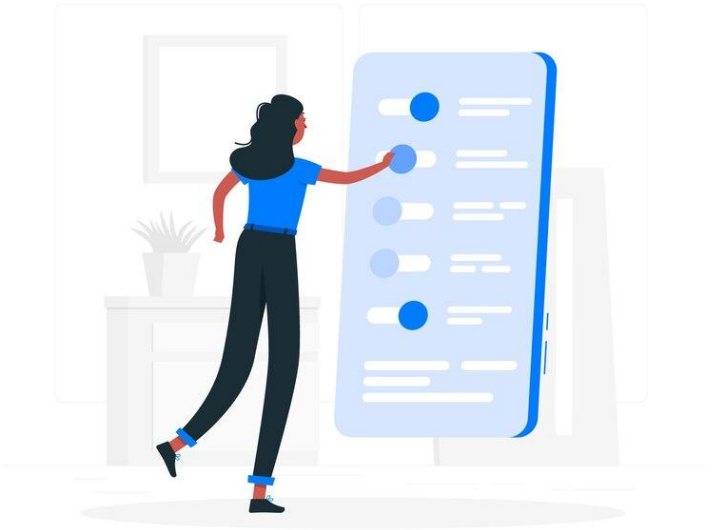
Contents



- Background
- The Symbio-Steel project
  - Main and specific objectives
  - Ambitions
  - Expected Results
- Monitoring and assessing the impact of Industrial Symbiosis initiatives
  - Developed Key Performance Indicators
- Conclusions

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Symbio-Steel newsletters

SymbioSteel newsletter subscription

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Background

The European Green Deal

- reaching climate neutrality by 2050
- foreseeing more sustainable management of materials and resources, according to Circular Economy and Industrial Symbiosis concepts.

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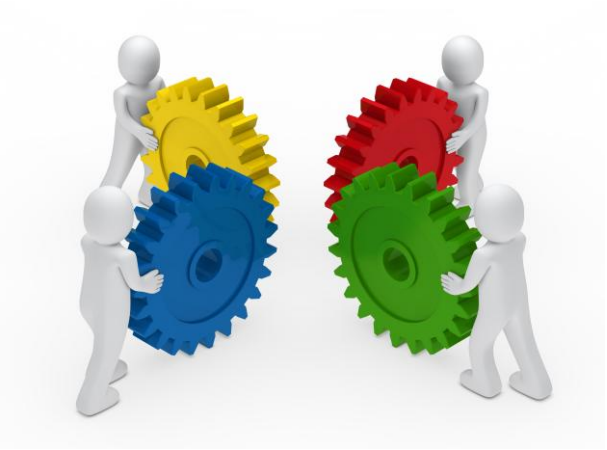

Industrial Symbiosis

- Transactions between different industry sectors, also involving technological and non-technological challenges.
- It concerns the use by one company or sector of underutilized resources from another.
- Its implementation results in:
  - reducing dependence on critical materials, mitigating supply risks
  - replacing virgin materials
    - reducing CO_2 emissions
    - transforming existing resources in the value chain into a usable form.

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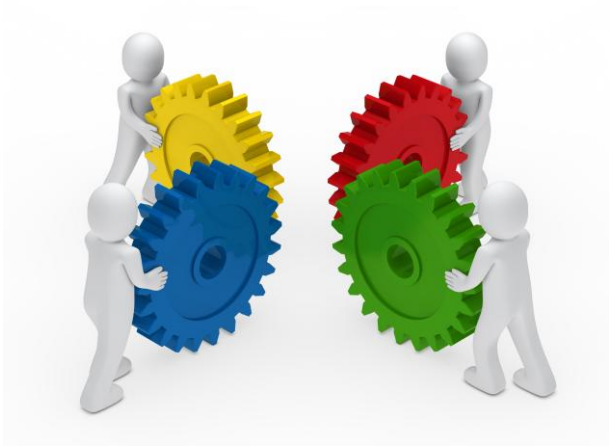
Background



Industrial Symbiosis

- The **EU steel industry** has been committed to Industrial Symbiosis implementation by:
  - avoiding waste production
  - re-using waste and by-products as resources, minimizing their production
  - exploiting by-products as a resource.

- Exploring Industrial Symbiosis between the steel sector and other industries

  → redefining inter-industry collaboration, enhancing resource efficiency, and fostering sustainability.

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The Symbio-Steel project

Objectives

Symbio-Steel will focus on the current state, upcoming techniques, and developments of Industrial Symbiosis implementation, to reach proactive cross-sectorial cooperation and integrations.

Overall objective:

paving the way to a wider uptake of Industrial Symbiosis solutions in the steel sector, exploiting and spreading knowledge on most promising and available results, supporting synergies with other industrial sectors.

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The Symbio-Steel project

Main objectives

- Monitoring and assessing impact of Industrial Symbiosis initiatives on steel sector.
- Assessing Industrial Symbiosis with respect to the transformation of steel industry to decarbonized next generation steelmaking.
- Development of guidelines on how to enhance Industrial Symbiosis in the steel industry.
- Meeting skills demands and attracting young talents.

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The Symbio-Steel project

Symbio-Steel aims at:

- analysing the achieved results related to the **Industrial Symbiosis**
- encouraging new opportunities
- creating **new synergies** and networks with other sectors
- identifying the main **drivers** and specific **barriers**
- identifying the main **impacts** on companies, environment, and society
- considering aspects and features of existing and new **networks** for new **decision-making**
- analysing research outcomes
- designing **dissemination** measures
- implementing **new synergies** addressing economic, environmental, and societal drivers.

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The Symbio-Steel project

Ambitions

- **dissemination** of achieved results, contributing to sector decarbonization and exploring new business opportunities
- **improving the analysis of projects and results**, also exploiting the possibility to apply to foreseen evolution of new steel production route
- **identifying the most promising technologies**, contributing to decarbonization and to optimize resource utilisation and energy efficiency in the steel sector
- **identifying technological and non-technological barriers** limiting the achieved results at industrial level implementation
- **identifying emerging technologies**, promoting their further contributions (e.g., facilitating the new consortia for new research proposals)
- identifying the **limits** (if any) **of current funding schemes** and provide suggestions to involved stakeholders
- **facilitating the dialogue among different production sectors** to exploit further possibilities of cooperations

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The Symbio-Steel project

Expected results

- Spreading most promising **research results**.
- Monitoring and assessing the impact of Industrial Symbiosis initiatives through selected and/or **elaborated KPIs**.
- Assessing and disseminating innovative Industrial Symbiosis solutions contributing to the transition towards **C-lean steel production**.
- Identifying **gaps and potential** for initiatives engaging different industrial sectors.
- Developing a virtual forum to **engage stakeholders** within and beyond steel.
- Developing **implementation scenarios** involving energy intensive industries.
- Providing **policy recommendations** to EC identifying the important future R&D issues and optimal use of funding opportunities.
- Providing **guidelines** on how to enhance uptake of Industrial Symbiosis in the steel sector by improving sector coupling.
- **Road mapping** to future Industrial Symbiosis with respect to next generation steelmaking.
- Supporting **attraction and retention of young talents** by involving them in workshops, webinars, and seminars.

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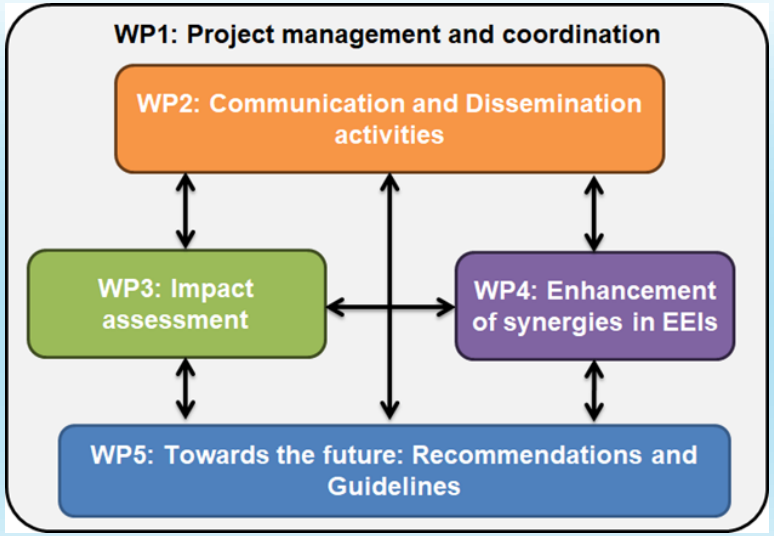
The Symbio-Steel project

The Work Plan

WP1	WP2	WP3	WP4	WP5
• Project management and coordination	• Communication and Dissemination activities	• Impact assessment	• Enhancement of synergies in EIIs	• Towards the future: Recommendations and Guidelines



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The Symbio-Steel project

Monitoring and assessing the impact of Industrial Symbiosis initiatives

- Selection *ad-hoc* defined relevant Key Performance Indicators (KPIs)
- Measuring the effectiveness of Industrial Symbiosis in the steel sector and in other energy-intensive industries
- Definition and selection of KPIs to be used within the Industrial Symbiosis context in iron and steelmaking and other energy- and CO_2-intensive sectors

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The Symbio-Steel project

Monitoring and assessing the impact of Industrial Symbiosis initiatives

List of KPIs related to the Symbio-Steel project	
KPI I	Energy efficiency
KPI II	Direct CO_2 emissions (Scope 1) reduction
KPI III	Reduction in virgin raw material usage
KPI IV	Enhancing the recycling of low-quality steel scrap
KPI V	Slag recycling rate
KPI VI	Dust and sludge recovery and reuse
KPI VII	Recycling rate of iron-rich residue streams
KPI VIII	Replacement rate of fossil carbon materials
KPI IX	CO_2 capture rate from process/off-gasses
KPI X	Share of carbon content in process gas (CO_2/CO) transformed into products
KPI XI	Technology readiness level

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Developed Key Performance Indicators

KPI (I): Heat Recovery

KPI definition (I)	
Name	Heat recovered.
Related to the process of iron and steelmaking	This applies to energy-intensive processes in iron and steelmaking, namely iron ore sintering, coke oven, BF, BOF, and EAF.
Description	This KPI measures the proportion of heat recovered and repurposed within an IS. It quantifies heat utilization efficiency, whereas another reuses one industry's by-product (residual heat).
Unit of measure	%
Expected impact	It enhances cost savings, reduces CO_2 emissions, and improves operational efficiency.
Notes	This includes all heat recovered and utilized by other industries in the IS.
	Heat recovery sources may include waste heat from furnaces, off-gases, or process residuals. High recovery rates indicate better energy efficiency and resource utilization.
	Necessary for compliance with environmental regulations related to energy use and emissions.
Formula:	
Share of heat recovered.	$\left(\frac{Recovered\ heat\ reused\ by\ other\ industries}{Total\ residual\ heat\ available}\right) \times 100\%$

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Developed Key Performance Indicators

KPI (II): Direct CO_2 emissions (Scope 1) reduction

KPI definition (II)	
Name	Direct CO_2 emissions (Scope 1) reduction.
Related to the process of iron and steelmaking	It can be applied to processes, namely iron ore sintering, pelletizing, cokemaking, the BF-BOF route, DRP, and EAF.
Description	KPI quantifies the reduction in Scope I CO_2 emissions (direct emissions) for industries participating in an IS. Specifically, it measures the direct CO_2 emissions avoided by one industry due to the reuse of CO_2 provided by another industry within the IS.
Unit of measure	%
Expected impact	CO_2 emissions reduction.
Notes	Only Scope I emissions reductions resulting directly from one industry's reuse of CO_2, as provided by another industry in the IS, can be considered.
	Indirect emissions (Scope II or III) should not be taken into account.
Formula:	
Scope 1: Direct specific CO_2 emission reduction	$\frac{CO_2\ reused\ by\ one\ of\ the\ industrial\ partners}{Initial\ (Scope\ I) CO_2 emissions} \times 100\%$

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Developed Key Performance Indicators

KPI (III): Reduction in virgin raw material usage

KPI definition (III)	
Name	Reduction in virgin raw material usage.
Related to the process of iron and steelmaking	This applies to processes that conventionally can rely on virgin raw materials (e.g., iron ore, coal, and limestone): iron ore sintering, pelletizing, cokemaking, BF, DRP, and EAF. IS practices: recycling and using by-products, can reduce virgin raw material consumption.
Description	Evaluate the decrease in virgin raw material usage (iron ore, coal, limestone) resulting from incorporating recycled inputs and IS practices. It reflects efforts to reduce resource dependency and improve material efficiency.
Unit of measure	%
Expected impact	Decreased dependency on virgin raw resources, cost savings, improved environmental situation, reduced mining impacts.
Notes	High reduction rates indicate effective recycling and material efficiency strategies. Contributes to resource conservation.
Formula:	
Reduction in virgin raw material usage	$\left(\frac{Virgin\ raw\ material\ reduction\ due\ to\ recycling}{Total\ virgin\ raw\ material\ used\ initially}\right) \times 100\%$

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Developed Key Performance Indicators

KPI (IV): Enhancing the recycling of low-quality steel scrap

KPI definition (IV)	
Name	Enhancing the recycling of low-quality steel scrap.
Related to the process of iron and steelmaking	This applies to steel scrap management processes, including pre-treatment, cleaning, and scrap yard management. It is relevant for BOF and EAF, where recycled steel scrap can replace pig iron or virgin steel.
Description	Increasing the usage of low-quality steel scrap grades (post-consumer) into high-quality steel grades. Replacing the use of pre-consumer grades with post-consumer low-quality steel scrap. Replacement of pig iron with post-consumer low-quality steel scrap to reduce reliance on virgin raw resources.
Unit of measure	%
Expected impact	Monitor the progress in the use of post-consumer scrap. Reduced dependency on virgin materials and decreased CO_2 emissions.
Notes	High replacement rates indicate effective recycling and integration of scrap materials. Supports reducing mining impacts and energy use associated with virgin iron production. Ensures sustainable steel production practices through better scrap utilization.
Formula:	
Change in post-consumer scrap use	$\left(\frac{Post-consumer\ scrap\ used\ in\ current\ period - post-consumer\ scrap\ used\ in\ baseline\ period}{Post-sonsumer\ scrap\ used\ in\ baseline\ period}\right) \times 100\%$
Pig iron replacement rate by post-consumer scrap	$\left(\frac{Post-consumer\ scrap\ used\ to\ replace\ pig\ iron}{Total\ pig\ iron\ used\ without\ substitution}\right) \times 100\%$

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Developed Key Performance Indicators

KPI (V): Slag recycling rate

KPI definition (V)	
Name	Slag recycling rate.
Related to the process of iron and steelmaking	This applies to slag generated in iron and steelmaking processes in BF, BOF, EAF, and LF.
Description	The proportion of repurposed slag generated can be used in applications such as cement production, construction aggregate, or fertilizer. This KPI tracks the effectiveness of slag recycling from BF, BOF, EAF, or LF initiatives and measures resource efficiency in by-product management.
Unit of measure	%
Expected impact	Reduces waste, lowers landfill use and cost, promotes CE practices, decreases raw material demand in other industries, and improves sustainability in steel production.
Notes	High recycling rates indicate the effective utilization of slag as a by-product.
	Slag recycling can reduce production costs in related industries by providing alternative raw materials.
	It is important to decrease the environmental and economic impacts of iron and steelmaking by diverting slag from landfills.
Formula:	
Slag recycling rate	$\left(\frac{Slag\ produced\ within\ the\ specific\ process\ (BF, BOF, EAF\ or\ LF)\ sent\ to\ recycling}{Total\ slag\ generated\ within\ the\ specific\ process\ (BF, BOF, EAF\ or\ LF)}\right) \times 100\%$

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Developed Key Performance Indicators

KPI (VI): Dust and sludge recovery and reuse

KPI definition (VI)	
Name	Dust and sludge recovery and reuse.
Related to the process of iron and steelmaking	This applies to processes in iron and steelmaking that generate dust and sludge, such as cokemaking, iron ore sintering, BF, BOF, and EAF.
Description	This KPI measures the effectiveness of managing dust and sludge generated in the production process by assessing reused and recycled fractions. It provides insight into the effectiveness of recycling technologies and waste management strategies (reducing reliance on landfills,maximizing the recovery of materials for reuse and recycling in production or other applications).
Unit of measure	%
Expected impact	Reduces landfill usage, minimizes environmental contamination, and supports resource efficiency.
Notes	It can also be used in other industrial applications, e.g. construction materials, as additives in other processes. Required for reducing waste.
Formula:	
Fraction of reused/recycled	$\left(\frac{Mass\ of\ reused/recycled\ fraction}{Total\ mass\ of\ dust\ and\ sludge\ generated}\right) \times 100\%$

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Developed Key Performance Indicators

KPI (VII): Recycling rate of iron-rich residue streams

KPI definition (VII)	
Name	Recycling rate of iron-rich residue streams.
Related to the process of iron and steelmaking	Iron-rich residues may come from various metallurgical processes, including BF and steelmaking dust, mill scale, and sludge.
Description	This KPI quantifies the proportion of iron-rich residues (e.g., mill scale, iron ore fines, dust, sludge) recycled and reintegrated into the iron and steelmaking process or other industrial applications.
Unit of measure	%
Expected impact	Recovering valuable iron content, reducing reliance on virgin iron ore. Reintegrating iron-rich residue into the production cycle.
Notes	Recycling methods can include direct reuse in iron ore sintering or BF or as raw materials in other industries (for instance, cement). Monitoring the KPI allows tracking progress in optimizing material efficiency.
Formula:	
Recycling rate	$\left(\frac{Mass\ of\ recycled\ iron-rich\ residues}{Total\ mass\ of\ iron-rich\ residues\ generated}\right) \times 100\%$

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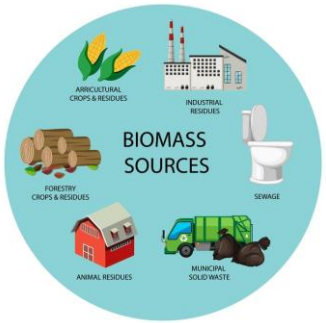
Developed Key Performance Indicators

KPI (VIII): Replacement rate of fossil carbon materials

KPI definition (VIII)	
Name	Replacement rate of fossil carbon materials.
Related to the process of iron and steelmaking	This applies to processes usually using fossil carbon sources, such as cokemaking, iron ore sintering, pelletizing, BF, and EAF, where alternative carbon materials can be introduced.
Description	Measures the extent to which fossil carbon materials, e.g., coal and coke, are replaced with alternative or renewable carbon materials. This KPI indicates progress toward reducing reliance on fossil fuels using biomass, raw or after mechanical treatment, heat treatment, biocoke, or recycled carbon sources, such as polymers.
Unit of measure	%
Expected impact	Reduced fossil fuel dependency and alignment with CO_2 emissions reduction.
Notes	High replacement rates suggest an effective transition to renewable or recycled carbon sources. Replacement sources include biomass, biochar, or other carbon-neutral/recycled carbon materials (e.g., polymers).
Formula:	
Replacement rate of fossil carbon materials	$\left(\frac{Amount\ of\ alternative\ carbon\ used}{Total\ carbon\ materials\ used}\right) \times 100\%$



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Developed Key Performance Indicators

KPI (IX): CO_2 from off-gases reuse

KPI definition (IX)	
Name	CO_2 from off-gases reuse.
Related to the process of iron and steelmaking	Processes that generate CO_2 emissions, such as cokemaking, iron ore sintering, BF, DRP, and EAF, and steel mill internal power plants, where off-gases can be captured for CO_2 reduction.
Description	Includes CO_2 recovered from industrial off-gases (e.g., flue gases, process emissions) and reused as a raw material for producing chemicals, e.g., methanol, urea, and carbonates, or combined with hydrogen to produce fuels (methane or methanol)
	Indicates the efficiency of CO_2 reuse.
Unit of measure	%
Expected impact	Reduction in CO_2 emissions.
Notes	Higher values indicate greater utilization of CO_2 from off-gases.
	Demonstrates the effectiveness of CO_2 utilization strategies.
	Supports collaboration between industries to optimize CO_2 usage.
Formula:	
CO_2 from off-gases reuse rate	$\left(\frac{Reused\ CO_2\ from\ off-gases}{Total\ CO_2\ emissions\ from\ off-gases}\right) \times 100\%$

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Developed Key Performance Indicators

KPI (X): Share of carbon content in process gas (CO_2/CO) transformed into products

KPI definition (X)	
Name	Share of carbon content in process gas (CO_2/CO) transformed into products.
Related to the process of iron and steelmaking	This applies to processes that generate CO_2/CO as off-gases, for instance, BF and smelting reduction, where carbon capture and utilization are possible.
Description	Measures the proportion of carbon content in process gases (CO_2/CO) that is captured and repurposed onto value-added products. This KPI tracks the effectiveness of CO_2/CO capture and utilization efforts, indicating progress toward reducing CO_2 emissions and enhancing resource efficiency.
Unit of measure	%
Expected impact	Reduced CO_2 emissions and enhanced resource efficiency contributed to CE objectives.
Notes	High transformation rates indicate effective utilization of captured CO_2/CO. It allows for the minimization of waste and the conversion of CO_2 emissions into useful products.
Formula:	
Share of carbon content in process gas (CO_2/CO) transformed into products	$\left(\frac{Carbon\ content\ in \frac{CO}{CO_2} used\ for\ products}{Total\ carbon\ content\ in \frac{CO}{CO_2}\ in\ process\ gas} \right) \times 100\%$

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Developed Key Performance Indicators

KPI (XI): Technology readiness level (TRL)

KPI definition (XI)	
Name	Technology readiness level.
Related to the process of iron and steelmaking	This applies to innovative technologies aimed at improving iron and steelmaking processes, such as emissions reduction technologies, energy efficiency measures, carbon capture, or new production methods.
Description	Measures the maturity of a technology, from initial concept (TRL 1) through to full operational use in a real-world environment (TRL 9). Indicates how close a technology is to deployment and operational integration.
Unit of measure	TRL scale.
Expected impact	Enables evaluation of new technologies progress. High TRL levels indicate readiness for implementation.
Notes	Regular assessments allow tracking of technology development and maturity over time.
	High TRL levels facilitate faster technology adoption, contributing to enhanced efficiency.
	TRL scores are based on established guidelines, ensuring a standardized measure of technology maturity.
Formula:	
Technology readiness level	Regular assessments are needed to determine their current TRL level for the projects where it is possible to apply.

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Conclusions on KPIs

- The defined KPIs address CO_2 emissions reduction, recycling rates, and resource reuse.
- Evaluating the implementation of IS, ensuring a consistent approach for analysis and reporting.
- Providing a starting point for monitoring and reporting the progress of relevant actions that the funded national, regional, and EU projects are taking to advance Industrial Symbiosis.
- Identifying new synergies with other industries and policy recommendations
- Achieving an effective industrial rollout of sector coupling technologies, in which the EU steel sector plays a central role

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SYMBIO STEEL

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