Technology database for synergy setups

Technology database template and guide for upgrading

JUNE 2019
Deliverable 3.2

Authors

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Organisation: ISQ

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Executive summary

This deliverable identifies and characterizes the procedures and technologies associated to the valorisation of the 100 Synergy types selected as most promising at European level in D3.1. The Technology database developed includes the description and technical characterization of both, implemented solutions at industrial scale and emerging technologies. Besides the procedure/technology characterization, relevant information to support its economic and environmental assessment (T3.5 and T3.4) is presented. The technical viability of the solutions presented considers its usability at industrial scale and its commercial availability as main decision criteria. The final evaluation of their European potential will be carried out in T3.6 and will include its economic, social and environmental impacts assessment.

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Abbreviations

BREF: Best Available Techniques Reference Document
BOF: Basic Oxygen Furnace
BF: Blast Furnace
BFG: Blast Furnace Gas
COG: Coke Oven Gas
DPM: Deodorized and sanitized Poultry Manure
EAF: Electrical Arc Furnaces
IS: Industrial symbiosis
LCP: Large Combustion Plant
ORC: Organic Ranking Cycle
P: Process
QTT: quantitative
QLT: qualitative
S: Sector
SS: Subsector
TDB: Technology Database
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Definitions

This section gives the definition of the main terms used in this deliverable.

Technology Database: Easy to access and organised data collection that Collection of data organized to be easy accessed and provide information related to the technical characterisation of procedures and technologies necessary required to the implementation of Industrial Symbiosis synergy types.

Synergy type: Type of synergy material/energy exchange that can be applied in the industries having the same output (for the sender industry) and input flows (for the receiver industry) and scaled up for the many different sites in Europe.

Direct synergies: Synergies cases where for which the “stream is directly used, or with light technology (e.g. crusher, packaging, transport, storage, collection/distribution), as a substitute from a raw one (substitution)” D3.1.

Indirect synergies: Synergies cases for which “the stream requires a modification or a treatment (e.g. extraction, separation, purification, cleaning or transformation) It can be done either by an involved stakeholder or a third party” D3.1.

Procedure: Correspond to the generic description of all a set of processes (including technologies) involved in a synergy type from the by-product/waste until its final recovery/utilization at the receiving sector. Note: the word “Procedure” was is used in substitution to the word “Technic” initially referred in the proposal of the project, in order to reduce possible misunderstandings due to its similarity with the word “Technology”.

Technology: Correspond to a specific equipment/ machine that allows to recover some element of interest from a flow with or without previous pre-treatment processes.

Post treatment: In case a technology is used, it corresponds to any necessary treatment necessary post technology application to improve the final quality of the element of interest or make the stream characteristics compliant with the receiver industry/process.

Transport: Correspond to specific needs for the stream transportation from sender to receiver industrial sector or facility involved in the synergy type.

Technical Viability: Correspond to the final technical assessment of procedures/technologies using evaluation criteria. Availability at commercial level and usability at industrial scale are the two main criteria analysed. Final GO or NO/GO decision confirms it’s the technical viability or not for synergy type valorisation.
Introduction

The SCALER Project major challenge is to scale up the uncovered potential behind physical resources by the valorisation of materials, infrastructures, logistics and technologies associated to intersectoral symbiotic relations at European level. The promotion of synergic processes between industrial sectors is deeply associated to the identification and characterization of the processes involved. Aiming to assess the full potential of the most promising, large scale, 100 intersectoral IS synergies types in Europe, SCALER WP3, divided into 6 interconnected tasks, targets the identification of the best available and emerging procedure and technologies for IS synergy type implementation by assuring their technical and economic viability as well as their positive environmental and social impacts.

Within the 100 synergies potential analysis, procedures and technologies play a crucial important role in the process. This deliverable (D3.2: Technology Database template and guide for update) introduces the results from T3.3 (Technology database for synergy setups). It details and provides the technical evaluation assessment ofon the procedures and technologies associated to the 100 synergies pre-identified in D3.1. The information presented for each synergy type includes: (i) the general description of the procedures and technologies; (ii) logistics and transportation overview and (iii) basic cost analysis needed to intersectoral stream valorisation. This valorisation considers the direct use of by-products by different receiving industrial sectors (with low technical complexity intermediary process required) or the indirect utilization of recovered elements of interest from raw by-products stream (with higher technical complex intermediary process associated).

The procedures and technologies were identified and evaluated with the support of available technical documents (BREFs, scientific publications, technical brochures, among other sources) as well as the inputs from Deliverable D2.2 (The role of intermediaries and key enabling technologies for ideation and implementation of industrial symbiosis). The deliverable outcomes will feed tasks T3.4, T3.5 and T3.6 namely environmental assessment, economic assessment and IS potential at European level. The final evaluation result from D3.1 on the technical viability analysis considers the commercial availability and development level together with industrial usability of valorisation procedures and technologies as main decision inputs.

This deliverable is organised as follows:

- Section 1 describes the TDB characterization, the main objective and the variables definition framework
- Section 2 details the methodological approach used to characterize the 100 procedures
- Section 3 provides the resume table of the procedures and technologies associated to the 100 synergy types
- Section 4 provides a statistical analysis and discussion of the TDB data regarding the technical evaluation of the 100 synergy types.
- Section 5 presents guidelines for TDB utilization and upgrading
- Section 6 presents the main conclusions of the present work

References are given in Section 7.
1. TDB characterization

1.1 Framework

In the sequence of previous task T3.2 and deliverable D3.1 (100 most promising synergy types definition) and looking for the main WP3 objective which is to assess their EU potential level (T3.6); a multicriteria decision-making process was defined, as can be seen in Figure 1. Each synergy type is analysed concerning three main factors: (i) its technical viability (T3.3); (ii) its economic potential (T3.4) and (iii) the environmental impacts (T3.4). The expected results obtained per task are finally defined as GO/NOGO decision (GO refers to a positive assessment and NOGO to a negative assessment) based on specific criteria, methodology and variables used. The selection of the most promising synergy types, which will be submitted to further and extensive environmental and economic assessment, results from the joint analysis of the above referred factors.

In this context, there are two main expected outputs from T3.3. To characterize and define the technical viability of the procedures/technologies and to provide required data for the environmental and socio-economic assessment. The expected result of task 3.3 is a single completed TDB, able to provide all necessary information including the general description of the relevant technologies, the associated synergies, the industrial sectors involved and quantitative data on associated investment and operating/operational costs. In this context, and considering the 100 synergy types involved and the dependences on provided data, three main objectives were defined for the TDB:

- i) Categorize the identified synergy typologies
- ii) Compile generic procedures and technologies per synergy category;
- iii) Estimate expected investment and operating costs.

To reach these objectives, three interconnected but independent data sets were created to organize and present the information. This separation allows the end users to analyse data in a structured and organized manner. Table 1 shows the links between objectives, data set identification and information provided.
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Table 1 - TDB Objectives and information of the datasets structure

<table>
<thead>
<tr>
<th>TDB Objective</th>
<th>Data set identification</th>
<th>Information provided</th>
<th>Input Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>i) Synergy Structure</td>
<td>Data set 1</td>
<td>Characterize the synergy type: Sender/Receiver/Technical Objective</td>
<td>T2.2 (Best Practices on IS); T2.3 (The role of Enabling Technologies); T3.2 (most IS promising cross-sectorial synergies).</td>
</tr>
<tr>
<td>ii) Procedures and technologies</td>
<td>Data set 2</td>
<td>Characterize Procedures/ Technologies, Logistics and their final technical viability assessment</td>
<td>BREF/PAPERS/TECHNICAL BROCHURES/BOOKS/OTHER SOURCES</td>
</tr>
<tr>
<td>iii) Characterization and Costs</td>
<td>Data set 3</td>
<td>Qualitative and quantitative data for cost analysis, inputs and outputs</td>
<td>BREF/PAPERS/TECHNICAL BROCHURES/BOOKS/OTHER SOURCES</td>
</tr>
</tbody>
</table>

Besides the two main outputs and technical objectives described before, the TDB template was developed to fulfil the lack of dedicated tools focused on procedure/technology characterization and decision-making support. In this context, several tools dedicated to resource mimicking/matching based on sender/user requirements are available at European level, but no support decision tools for procedure/technology selection were found. The same situation was found on the unavailability of integrated information sources to fully support decision process. In this sense, the TDB compiles qualitative, quantitative and relevant contextualization information for decision making on technology selection. The TDB was also developed thinking on the future connectivity between multi IS platforms using common identification references and flexible search keywords based on the by-product, sender/receiver process or element of interest.

1.2 Variable definition

The TDB variables definition process considered two complementary approaches; i) the information presented should provide inputs for the three datasets characterization and technical viability analysis; ii) provide technical information for the economic and environmental impacts assessment. Figure 2 resumes the multivariable approach scheme considering TDB variables outputs.

![TDB VARIABLES Definition](image)

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To solve the requirements on variable definition, quantitative (QTT) and qualitative (QLT) variables are considered. QTT variables refer to those inputs needed for specific calculations and quantitative evaluations. QLT variables are those associated to support decisions and general understandings associated to the process or technologies. QTT variables are mostly required to support the economic and life cycle assessment. Major part of gathered information is QLT and was divided all over the 3 datasets. Table 2 resumes all variables included in the TDB, their association with the datasets, the information provided by their analysis, their characterization as QTT or QLT, the inputs source and the expected end users within the project.
### Table 2 - Resume table of variables used in the TDB template

<table>
<thead>
<tr>
<th>VARIABLE NAME</th>
<th>DATA SET</th>
<th>INFORMATION PROVIDED</th>
<th>QTT</th>
<th>QLT</th>
<th>INPUT INFO. SOURCE</th>
<th>END USER</th>
</tr>
</thead>
<tbody>
<tr>
<td>SYNERGY ID NUMBER</td>
<td>1</td>
<td>Synergy ID</td>
<td>N.A.</td>
<td>N.A.</td>
<td>D 3.1</td>
<td>WP3</td>
</tr>
<tr>
<td>BY-PRODUCT</td>
<td>1</td>
<td>by-product ID</td>
<td>X</td>
<td>D 3.1</td>
<td>WP3</td>
<td></td>
</tr>
<tr>
<td>STATE OF MATTER</td>
<td>1</td>
<td>ID Physical State of the by-product</td>
<td>X</td>
<td>D 3.1</td>
<td>WP3</td>
<td></td>
</tr>
<tr>
<td>ELEMENT OF INTEREST</td>
<td>1</td>
<td>Defines which is the valuable part to recover from by-product</td>
<td>X</td>
<td>D 3.1</td>
<td>WP3</td>
<td></td>
</tr>
<tr>
<td>SENDER SECTOR AND PROCESS</td>
<td>1</td>
<td>Defines synergy sender sector and process</td>
<td>X</td>
<td>D 3.1</td>
<td>WP3</td>
<td></td>
</tr>
<tr>
<td>RECEIVER SECTOR AND PROCESS</td>
<td>1</td>
<td>Defines synergy receiver sector and process</td>
<td>X</td>
<td>D 3.1</td>
<td>WP3</td>
<td></td>
</tr>
<tr>
<td>TECHNICAL OBJECTIVE</td>
<td>1</td>
<td>Resumes the technical objective of the procedure or technology</td>
<td>X</td>
<td>D 3.1</td>
<td>WP3</td>
<td></td>
</tr>
<tr>
<td>RESOURCE EXCHANGED</td>
<td>1</td>
<td>Defines if energy/water or materials were exchanged</td>
<td>X</td>
<td>D 3.1</td>
<td>WP3</td>
<td></td>
</tr>
<tr>
<td>TYPE OF SYNERGY</td>
<td>1</td>
<td>Defines if the synergy is DIRECT/INDIRECT</td>
<td>X</td>
<td>D 3.1</td>
<td>WP3</td>
<td></td>
</tr>
<tr>
<td>IDENTIFICATION SOURCE</td>
<td>1</td>
<td>Describe the identification sources on synergy validation</td>
<td>X</td>
<td>D 3.1</td>
<td>WP3</td>
<td></td>
</tr>
<tr>
<td>IDENTIFICATION</td>
<td>2</td>
<td>An equation resumes the various processes involved Pre-treatment (PT), Technology (T) and Post treatment (POT)</td>
<td>X</td>
<td>Own methodology</td>
<td>T3.4</td>
<td></td>
</tr>
<tr>
<td>PROCEDURE (P) (Name and description)</td>
<td>2</td>
<td>Generic description of all processes involved from the by-product/waste stream until its final recovery/utilization use</td>
<td>X</td>
<td>BREF/papers/ technical brochures/books/other sources</td>
<td>T3.4</td>
<td></td>
</tr>
<tr>
<td>TECHNOLOGY (T) (Name and description)</td>
<td>2</td>
<td>Describes if the technology/equipment that allows the valorisation process is applicable</td>
<td>X</td>
<td>BREF/papers/ technical brochures/books/other sources</td>
<td>T3.4</td>
<td></td>
</tr>
<tr>
<td>POST TREATMENT (POT) (YES/NO and description)</td>
<td>2</td>
<td>In case a technology is used, it describes any treatment necessary post technology application. A initial YES/NO define need on Non Applicability</td>
<td>X</td>
<td>BREF/papers/ technical brochures/books/other sources</td>
<td>T3.4</td>
<td></td>
</tr>
<tr>
<td>COMPLEMENTARY INFORMATION</td>
<td>2</td>
<td>Any other relevant information concerning P/T/POT interpretation</td>
<td>X</td>
<td>BREF/papers/ technical brochures/books/other sources</td>
<td>T3.4</td>
<td></td>
</tr>
<tr>
<td>CHARACTERIZATION (Identification)</td>
<td>2</td>
<td>Identify if the following analysis correspond to the full procedure (P) or Technology (T) previous presented.</td>
<td>X</td>
<td>Own methodology</td>
<td>T3.4 ; T3.5 ; T3.6</td>
<td></td>
</tr>
<tr>
<td>CHARACTERIZATION (Site/Ext Facility/receiver)</td>
<td>2</td>
<td>Identify where can the Procedure or Technology take place. Sender site, external intermediary facility or receiver site.</td>
<td>X</td>
<td>Own methodology</td>
<td>T3.4 ; T3.5 ; T3.6</td>
<td></td>
</tr>
<tr>
<td>CHARACTERIZATION (Yield range)</td>
<td>2</td>
<td>Corresponds to the productivity that a Procedure or Technology can achieve in a defined period of time. All data obtained is referenced to the origin source</td>
<td>X</td>
<td>BREF/papers/ technical brochures/books/other sources</td>
<td>T3.5 ; T3.6</td>
<td></td>
</tr>
<tr>
<td>CHARACTERIZATION (Recovery rate)</td>
<td>2</td>
<td>Corresponds to the maximum amount of the element of interest/ by-product that can be valorised from the by-product/waste stream. All data obtained is referenced to the origin source</td>
<td>X</td>
<td>BREF/papers/ technical brochures/books/other sources</td>
<td>T3.5 ; T3.6</td>
<td></td>
</tr>
<tr>
<td>TRANSPORTAT (YES/NO/N.A.)</td>
<td>2</td>
<td>Identifies the needs or non-applicability on transport requirements</td>
<td>X</td>
<td>BREF/papers/ technical brochures/books/other sources</td>
<td>T3.4 ; T3.5 ; T3.6</td>
<td></td>
</tr>
<tr>
<td>MEAN OF TRANSPORT</td>
<td>2</td>
<td>Identifies the possible means of transportation associated to the by-product or element of interest. Boat transportation was not considered in the actual analysis at European level.</td>
<td>X</td>
<td>BREF/papers/ technical brochures/books/other sources</td>
<td>T3.4 ; T3.5 ; T3.6</td>
<td></td>
</tr>
<tr>
<td>DESCRIPTION</td>
<td>2</td>
<td>Describes specificities or approaches dealing with transportation</td>
<td>X</td>
<td>BREF/papers/ technical brochures/books/other sources</td>
<td>T3.4 ; T3.5 ; T3.6</td>
<td></td>
</tr>
<tr>
<td>AVAILABILITY - Commercially available</td>
<td>2</td>
<td>Identifies with a YES/NO result if the procedure/technology is commercially available. The result obtained is referenced to the origin source</td>
<td>X</td>
<td>BREF/papers/ technical brochures/books/other sources</td>
<td>T3.5 ; T3.6</td>
<td></td>
</tr>
<tr>
<td>USABILITY - Industrial scale</td>
<td>2</td>
<td>Identifies with a YES/NO result if the procedure/technology is already used at industrial scale. The result obtained is referenced to the origin source</td>
<td>X</td>
<td>BREF/papers/ technical brochures/books/other sources</td>
<td>T3.5 ; T3.6</td>
<td></td>
</tr>
<tr>
<td>FINAL COMMENTS</td>
<td>2</td>
<td>Any other relevant information concerning previous viability analysis interpretation</td>
<td>X</td>
<td>BREF/papers/ technical brochures/books/other sources</td>
<td>T3.5 ; T3.6</td>
<td></td>
</tr>
<tr>
<td>GO/NOGO (Technical viability)</td>
<td>2</td>
<td>Shows the final technical viability assessment results (GO/NOGO). This input will be used for the final assessment together with the socio-economic and environmental assessment.</td>
<td>X</td>
<td>BREF/papers/ technical brochures/books/other sources</td>
<td>T3.6</td>
<td></td>
</tr>
<tr>
<td>VARIABLE NAME</td>
<td>DATA SET</td>
<td>INFORMATION PROVIDED</td>
<td>QFT</td>
<td>QLT</td>
<td>INPUT INFO. SOURCE</td>
<td>END USER</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>----------</td>
<td>---------------------------------------------------------------------------------------</td>
<td>-----</td>
<td>-----</td>
<td>-----------------------------------------</td>
<td>----------</td>
</tr>
<tr>
<td>PROCEDURE/TRANSPORT</td>
<td>3</td>
<td>Identifies the most relevant cost associated to the valorisation process to support decision making</td>
<td>X</td>
<td></td>
<td>Own methodology</td>
<td>T3.5, Industrie s</td>
</tr>
<tr>
<td>REQUIRED SPECIFICATIONS</td>
<td>3</td>
<td>Refers to generic requirements of the technology or procedure. Can deal with by-products or other inputs</td>
<td>X</td>
<td></td>
<td>BREF/papers/technical brochures/books/other sources</td>
<td>T3.4</td>
</tr>
<tr>
<td>HEAT DEMAND</td>
<td>3</td>
<td>Defines the heat demand associated to the selected procedure/technology. Fuel or electrical requirements can be considered. The results presented are referenced to the origin source.</td>
<td>X</td>
<td></td>
<td>BREF/papers/technical brochures/books/other sources</td>
<td>T3.4</td>
</tr>
<tr>
<td>ELECTRICITY DEMAND</td>
<td>3</td>
<td>Defines the electricity demand associated to the selected procedure/technology. The results presented are referenced to the origin source.</td>
<td>X</td>
<td></td>
<td>BREF/papers/technical brochures/books/other sources</td>
<td>T3.4</td>
</tr>
<tr>
<td>WATER DEMAND</td>
<td>3</td>
<td>Defines the water demand associated to the selected procedure/technology. The results presented are referenced to the origin source.</td>
<td>X</td>
<td></td>
<td>BREF/papers/technical brochures/books/other sources</td>
<td>T3.4</td>
</tr>
<tr>
<td>OTHER NECESSARY PRODUCTS</td>
<td>3</td>
<td>Defines the needs on any material/product required for the selected procedure/technology. The results presented are referenced to the origin source.</td>
<td>X</td>
<td></td>
<td>BREF/papers/technical brochures/books/other sources</td>
<td>T3.4</td>
</tr>
<tr>
<td>OPEX (Range)</td>
<td>3</td>
<td>Refers to the operational expenditure associated to the procedure/technology operation. The results presented are referenced to the origin source.</td>
<td>X</td>
<td></td>
<td>BREF/papers/technical brochures/books/other sources</td>
<td>T5.5, Industrie s</td>
</tr>
<tr>
<td>CAPEX (Range)</td>
<td>3</td>
<td>Refers to the capital expenditure associated to the procedure/technology implementation. The results presented are referenced to the origin source.</td>
<td>X</td>
<td></td>
<td>BREF/papers/technical brochures/books/other sources</td>
<td>T5.5, Industrie s</td>
</tr>
<tr>
<td>RO/P/B/P/LIFE/EFULL LIFE</td>
<td>3</td>
<td>Return of Investment, Pay Back Period or Useful Life of procedure/technologies are considered as alternative cost evaluation data sources to OPEX/CAPEX. The results presented are referenced to the origin source.</td>
<td>X</td>
<td></td>
<td>BREF/papers/technical brochures/books/other sources</td>
<td>T5.5, Industrie s</td>
</tr>
<tr>
<td>COMMENTS</td>
<td>3</td>
<td>Any other relevant information concerning previous economic analysis interpretation</td>
<td>X</td>
<td></td>
<td>BREF/papers/technical brochures/books/other sources</td>
<td>T5.5, Industrie s</td>
</tr>
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<td>CO2 EMISSIONS</td>
<td>3</td>
<td>Refers to the emissions of CO2 associated to the procedure/technology used</td>
<td>X</td>
<td></td>
<td>BREF/papers/technical brochures/books/other sources</td>
<td>T3.4</td>
</tr>
<tr>
<td>RESIDUES</td>
<td>3</td>
<td>Refers to the produced residues associated to the procedure/technology used</td>
<td>X</td>
<td></td>
<td>BREF/papers/technical brochures/books/other sources</td>
<td>T3.4</td>
</tr>
<tr>
<td>OTHER RELEVANT PRODUCTS</td>
<td>3</td>
<td>Refers to any other products/by-products produced by procedure/technology used</td>
<td>X</td>
<td></td>
<td>BREF/papers/technical brochures/books/other sources</td>
<td>T3.4</td>
</tr>
</tbody>
</table>

(1) N.A.: Not Applicable

(2) Own methodology: Frameworks/methodologies developed internally in T3.3 without access to external sources.
2. Methodology

2.1 General approach

Once the required variables were defined, a systematic methodological approach was needed to obtain the correspondent data and characterize each procedure and technology associated to the 100 synergy types. Figure 3 resumes the sequential steps and the three information levels of information of the methodological approach used for TDB data completion.

Starting from the initial list of 100 synergy types, the first level considered three main steps:

- The first one compiled and analysed all information available from D3.1 and looked for any incoherence in synergy identification. The final objective was to create a global understanding of the synergy flow and processes for further analysis. During the analysis, some information duplicities were found due to synergy similarities, a problem solved by information exchange and data crosscheck.
- The second step identified and characterised in detail the raw by-product, the sender sector, the production process involved and their technical and physicochemical properties (BREF documents were the main source of information).
- The third step focused on the analysis of the quantity and quality requirements needed in the receiving sector/process. The identification and validation of compatibilities between raw by-products and elements of interest between sectors/processes is a core stage (Level 1).

Due to the variability of sender and receiver sector processes, states of matter and elements of interest involved on the 100 synergy types, several technical issues requiring further research were identified. Innovative synergies discovered by Strane methodology within the work carried out in Tasks T3.1 and T3.2 were the most challenging as no significant literature background was available.
Once the sectors/processes, by-products and elements of interest involved were clearly identified, the next level (Level 2) focused on the identification of procedures and technologies associated to a possible valorisation and further synergy validation. In this context, it is important to differentiate between procedure and technology (See section 2.2). In resume, procedure refers to a full set of processes/steps from initial raw by-product to the final recovery/valorisation of elements, while technology refers solely to a specific and dedicated process/machine with a specific technical purpose. During the analysis carried out, existing and emerging procedures and technologies were considered to increase the scope of the TDB. Together with a further logistic analysis based on by-product transportation requirements, two main results outcomes from this stage: (i) the final technical viability analysis (considering its usability and availability) and (ii) the key cost identification (Procedure/Technology or transportation).

The third Level, focused on the INPUT and OUTPUT characterization of the procedure/technologies and the identification of associated implementation and operation costs. All variables presented in section 1.2, were characterized in the TDB template and all origin sources of information referenced.

### 2.2 Direct/Indirect Synergies

From deliverable D3.1, a full set of 100 synergy types was the main input for the work undertaken in task T3.3. Besides the different sectors and technical aspects, an important differentiation was established before further characterization. Synergies were classified in two groups:

- **Direct synergies**, corresponding to cases where the "stream is directly used, or with light technology (e.g. crusher, packaging, transport, storage, collection/distribution), as a substitute from a raw one (substitution)",
- **Indirect synergies**, "if the stream requires a modification or a treatment (e.g. extraction, separation, purification, cleaning or transformation) It can be done either by an involved stakeholder or a third party “(Scaler D3.1).

Considering that the main objective of task T3.3 was the full characterization of synergy processes and technologies, the differentiation between direct and indirect synergy types required two different approaches for their technological characterization. The following subsections focus individually these two approaches.

#### 2.2.1 Indirect Synergies

Initially 52 out of 100 synergy types were considered indirect before the technical viability analysis on task T3.3. Figure 4 shows the logic behind the indirect synergies interpretation used during the technical characterization.

**Figure 3 – Interpretation of indirect synergy types**

![Diagram of indirect synergy types](image-url)
Deliverable 3.2

The sender sector, normally associated to a specific industrial site (Industry 1) emits a by-product A1 which contains valuable elements of interest (B1) that can be recovered (B2) and used by Industry 2, the identified receiver site. To extract those elements of interest it is necessary to implement a procedure (P). This procedure considers all processes associated with such valorisation. Three main stages can be generally associated to a procedure:

(i) a pre-treatment (PT) stage where different processes can be applied to the by-product A1;
(ii) a specific recovery technology (T) to recover the element of interest after required pre-treatment processes;
(iii) a post-treatment (PT) process in case specific actions should be necessary after technology application and before its final utilization.

Figure 5 shows the three possible valorisation routes for indirect synergy types procedure valorisation.

![Figure 4 – Valorisation routes for Indirect Synergy types procedure stages](image)

Even though all stages can be part of the procedure, their applicability will be always associated to the specificities of each synergy type. To simplify the identification of the stages involved in each procedure (variable identification of the TDB), Equation 1 is used to define the generic indirect synergy type stages.

\[
\text{Eq. 1} \quad \text{Procedure } (P) = \text{Pre Treatment (PT)} + \text{Technology (T)} + \text{Post Treatment (PT)}
\]

Note that the identification of variables at the TDB use the above presented nomenclature for process identification.

2.2.2 Direct Synergies

From the 100 synergy types 48 were initially identified as direct. In the opposite to indirect synergies, the main focus is not the recovery of a particular element (B1) but mostly the direct utilization of the by-product (A1) from Industry 1 to Industry 2 without significant changes on its original physicochemical constitution. In this procedure, some basic mechanical and physicochemical treatment might be necessary before its utilization in Industry 2, together with transportation. These are the most relevant processes associated to the procedure (P). Figure 6 resumes the schematic valorisation steps involved in direct synergy type.
For synergies where basic procedures are necessary before by-product final utilization, these can be considered as pre-treatment (PT) or technology (T). Pre-treatment will refer to a group of sequential process that cannot be dissociated from each other, while technology corresponds to a single process associated to a specific equipment that will perform independently. As shown in Figure 7 by-product utilization is the focus for direct synergy types and no post treatment is considered. In the cases where, through deeper research, a complex technology/procedure (type, quantity of equipment/machine/treatment, investment required) was identified to treat the flow and recover the element, the synergy classification was updated to indirect.

It should be noted that the considered complexity level of the procedure/technology necessary for the implementation of each specific synergy type might be of subjective nature or depend on the level of integration in any given industrial sector. For instance, a procedure/technology could be already being implemented in an industrial sector but with limitations, or higher complexity, in another industrial sector.

Moreover, it is possible to identify cases where no specific elements of interest need to be recovered but rather the removal of certain components/impurities that otherwise prevent or greatly reduce the valorisation potential of the by-product. In this case, the synergy could be also changed to indirect, although its direct valorisation was also possible with certain limitations. As an example, substantial manufacturing adaptations (equipment or process) affecting the quality of the final product and therefore its application level.

Nonetheless, the generic indirect synergy in all TDB is defined by Equation 2. Note that the identification of variables at the TDB use the presented nomenclature for process identification:

Eq 2. Procedure \((P) = Pre\ Treatment\ or\ Technology\ (T)\)
2.2.3 Application on TDB

In the sequence of the synergy classification criteria presented in the previous section, some necessary practical approaches for its characterization and use were established. Table 3 resumes the different methodological approaches used for Direct and Indirect synergy type analysis.

<table>
<thead>
<tr>
<th>Synergy Type</th>
<th>Main Focus</th>
<th>Technical Complexity</th>
<th>Procedure Involved</th>
<th>Quantitative Variables</th>
<th>Cost Analysis</th>
<th>Clustering Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indirect</td>
<td>Element recovery</td>
<td>High</td>
<td>PT + T + POT</td>
<td>Yield / Recovery rates/ Heat/Electricity/Water</td>
<td>OPEX /CAPEX / Transport</td>
<td>By sender sector</td>
</tr>
<tr>
<td>Direct</td>
<td>By-product Utilization</td>
<td>Low</td>
<td>P or T</td>
<td>Mostly N.A Recovery rates*</td>
<td>OPEX/CAPEX* Transport</td>
<td>By receiver sector</td>
</tr>
</tbody>
</table>

*Only available for synergies with technology associated

Indirect synergies valorisation routes are mostly based on element recovery rather than by-product utilization. The associated procedures includes a wide variety of processes and technologies involved with higher technical complexity levels. Capital and operational costs must be considered to procedure/technology characterization, and quantitative key data should include technology yield and recovery rates.

To simplify synergy technical analysis and further data acquisition, indirect synergy types were initially sub grouped by sender sector. This approach was used since element recovery is highly dependent on raw by-product characteristics (associated to sender sector and process). The receiver sector is mostly an end user of the recovered element of interest. This methodology intends to agile the analysis of technical documentation often available by industrial sector. In short, the presented subgrouping was used to simplify the analysis of Step 2 in Level 1 (Figure 3).

Direct synergy types valorisation routes are mostly based on by-product utilization. Basic pre-treatment and technological procedures might be associated, while transportation is the main process involved and main cost source. Since the by-products could be directly used at receiver site, capital costs are not suitable for analysis and operational costs would be very similar to the baseline scenario traditionally used. As no technology is associated to the valorisation process, quantitative data will not consider technology yield and recovery rates. Moreover, the industrial scale usability concerning the viability resume of Direct Synergies was shifted towards the actual implementation of the synergy. In the majority of cases, no technology is being associated with direct synergies, only transportation steps.

To simplify synergy technical analysis and further data acquisition, direct synergy types were initially subgrouped by receiver sector. By contrats to indirect synergies, raw by-product should be directly used at receiver sector. As no significant changes on the physicochemical characteristics are required, the most important fact is the compliance with receiver sector physicochemical composition criteria. This methodology intends to agile the analysis of technical documentation often available by industrial sector. In resume, the presented sub-grouping was used to simplify the analysis of Step 3 in Level 1 (Figure 3).
3. Technologies Database

Even the technology database is presented in PDF format. The full excel file will be publicly available to facilitate its access, consultation and future improvements. The results presented are divided in two individuals excel sheets, the TDB Direct and TDB Indirect. Indirect TDB sheet is grouped by sender sector as previously introduced, while direct TDB is organized by receiver sector. All data presented correspond to information available before May 2019.

Note: In the TDB, N.A. and N.F. refers respectively to “Not Applicable” and to “Not Found”.
Eddy current Separators allow the recovery of electrically conductive materials, such as non-ferrous metals. The magnets on the rotor surface generates an eddy current inside electrically conductive particles which

Acid Leaching - Ion

The aim of this synergy is to recover hydrogen from sodium chlorate production. The formation of chlorate process and provide and recover sulphuric acid, as a by-

Combustion

Traditional methods for pgm recovery from spent catalyst involve the use of Acid leaching and Precipitation processes. However, recent advances involve the use of Acid

P : VACUUM DISTILLATION

Sulphuric acid recovery is already a standard procedure in the copper smelting process

S : REFINING_MINERAL_OIL_AND_GAS

process conditions should be tested for optimal process operation. For this reason, no detailed information could be given for the economic analysis. A recovery rate of 98%
The aim of this synergy is to produce conventional fuels, electricity and heat for urban heating. These technologies include the use of direct electrical conversion devices to recover waste heat and directly reuse it.

Direct electrical conversion devices: Thermoelectric, piezoelectric, thermionic, and thermophotovoltaic devices recover the waste heat and convert it into electrical energy. These devices convert waste heat to electrical energy. Thermoelectric devices, for example, consist of two different materials that are connected electrically and thermally. Waste heat causes the temperature difference between the two materials and generates an electrical current.

Mechanical treatment processes are used to homogenize hazardous liquid/pasty wastes to recover energy content and recycle inorganic material. Blending and homogenization are the main operations, pretreatment activities to prepare waste for further treatment.

Highly dependent on the nature of the waste, the valorization rates will be different processes. The average energy content per ton of waste can range from 100 kWh/t to 1000 kWh/t, depending on the type of fuel produced (e.g., ash, gas, liquid, solid fuel).

Two main steam sources can be distributed: High pressure steam and Low pressure steam. The design of the distribution network will be highly dependent on it. Lower pressure systems have the advantages: there is less loss of energy at boiler level and in the distribution system; the amount of remaining energy in the condensate is used in conventional heat transport system at industrial sites. Distance is the key factor for transport viability evaluation.

For thermodynamic cycles, transport technology for waste heat is the same as for conventional energy sources. Selection of transport technology depends on the actual development stage, benefits and costs, and on the type of fuel.

An increase in amount of waste and processing capacity means the decrease in costs of waste treatment. Table 1 (H. Jouhara et al. 2008) shows a summary of guidance for equipment capacities and the type of fuel selected for the process used. See Table 2 (H. Jouhara et al. 2008) for individual description of fine (biologically degradable) fraction.

Table 5.34 compiled different recovery systems/technologies for energy production.
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>SALT SOLID</td>
<td>N.A. No specific technology is associated N.A. N.A.</td>
<td>N.A. N.A. N.A.</td>
<td>N.A. N.A. N.A.</td>
<td>N.A. N.A. N.A.</td>
<td>N.A. N.A. N.A.</td>
<td>N.A. N.A. N.A.</td>
<td>N.A. N.A. N.A.</td>
<td>N.A. N.A. N.A.</td>
<td>N.A. N.A. N.A.</td>
<td>N.A. N.A. N.A.</td>
</tr>
</tbody>
</table>

The purpose of this synergy is to provide industries with fuels from industrial wastes rather than using processes and treat it to be suitable as a raw material for the production of cement. Its chemical composition is mainly composed of Fe₂O₃ and Al₂O₃ as well as some silica, rendering it suitable as a raw material for the production of cement. Due to the distinct type of refractories used in steel and glass industry furnaces, the technology available for sorting will not allow for pre-sorting. So far it has only been applied widely for a very limited number of materials such as MgO-C refractories.

The solution with NaCl could be sent directly to sodium electrolysis to remove impurities from sodium carbonate which could be used to substitute lime as a raw material for the production of cement. No post treatment is considered for the cement industry.

Gypsum is available in two forms. White Gypsum being gypsum in its pure form has good commercial viable and could be sold as a raw material for various industries. Current utilizations of lime sludge from sugar beet production are as a soil amendment to stabilize soil pH and to improve soil structure. Other less

High grade Iron ores (60-70% Fe) are used as feed for the pelletization process. Low-grade ores (40% Fe) requires a beneficiation process in order to take advantage of the potential benefits of recycling spent refractory materials, correct recovery and treatment of scrap refractory

The coke can be reused in the receiver sector, but there is no information on how to transport it. (BREF WT)

Transport of sludge should be avoided as much as possible. Dried sludge or sludge could potentially be used for co-incineration processes, co-incineration of sludges is a common practice in Europe. Generally the sludge residue is co-incinerated with coal or municipal solid waste (MSW). In order to take advantage of the potential benefits of recycling spent refractory materials, correct recovery and treatment of scrap refractory, sludge could potentially be compliant with its utilization if metal oxide compositions are within acceptable limits for calcium carbide.

The wood has to be secured sufficiently and the cargo

The feasibility of this receiver sector depends on the percentage of sludge that can be utilized. BREF_PP YES BREF_PP

Simplified economic analysis showed that the profits per ton of sludge are significantly lower than the costs of the sodium electrolysis process.

Transport of sludge depends on the state of the sludge, if dried avoid spreading it in the environment. Dependent on the percentage of sludge that can be utilized, BREF_PP YES BREF_PP

Water may be conveyed through pipelines by gravity flow after cleaning. The BF gas contains normally levels of dust and soluble components that must be controlled before entering the receiver sector. (blending), which is necessary to store the gas oil-cleaning units, either a self-cleaning separator.

No specific technology is required besides drying and pelletizing. These operations were considered to be part of the retreatment of the sludge. N.A. No specific technology required N.A. N.A.

No post treatment is considered for the cement industry. No additional treatment or processing is required for the utilization of the sludge. N.A. No specific technology is associated N.A. N.A.

Depends on the percentage of sludge that can be utilized, BREF_PP YES BREF_PP

The purpose of this synergy is to recover salt from non-food waste streams. The solution with NaCl could be sent directly to sodium electrolysis to remove impurities from sodium carbonate which could be used to substitute lime as a raw material for the production of cement. Sodium electrolysis is integrated to remove impurities from sodium carbonate which could be used to substitute lime as a raw material for the production of cement. No post treatment is considered for the cement industry.

Gypsum is available in two forms. White Gypsum being gypsum in its pure form has good commercial viable and could be sold as a raw material for various industries. Current utilizations of lime sludge from sugar beet production are as a soil amendment to stabilize soil pH and to improve soil structure. Other less

High grade Iron ores (60-70% Fe) are used as feed for the pelletization process. Low-grade ores (40% Fe) requires a beneficiation process in order to take advantage of the potential benefits of recycling spent refractory materials, correct recovery and treatment of scrap refractory

The coke can be reused in the receiver sector, but there is no information on how to transport it. (BREF WT)

Transport of sludge should be avoided as much as possible. Dried sludge or sludge could potentially be used for co-incineration processes, co-incineration of sludges is a common practice in Europe. Generally the sludge residue is co-incinerated with coal or municipal solid waste (MSW). In order to take advantage of the potential benefits of recycling spent refractory materials, correct recovery and treatment of scrap refractory, sludge could potentially be compliant with its utilization if metal oxide compositions are within acceptable limits for calcium carbide.

The wood has to be secured sufficiently and the cargo

The feasibility of this receiver sector depends on the percentage of sludge that can be utilized. BREF_PP YES BREF_PP

Simplified economic analysis showed that the profits per ton of sludge are significantly lower than the costs of the sodium electrolysis process.

Transport of sludge depends on the state of the sludge, if dried avoid spreading it in the environment. Dependent on the percentage of sludge that can be utilized, BREF_PP YES BREF_PP

Water may be conveyed through pipelines by gravity flow after cleaning. The BF gas contains normally levels of dust and soluble components that must be controlled before entering the receiver sector. (blending), which is necessary to store the gas oil-cleaning units, either a self-cleaning separator.
4. Analysis of technologies

A statistical analysis was carried out to compile the most relevant results.

From the 100 Synergy types generated from D3.1 (52 indirect and 48 direct), 16% were finally considered as technically NO/GO and 84% as GO (Figure 8). From the sixteen synergies evaluated as NO/GO, eight were initially direct and eight indirect where 87.5% of the indirect NO/GO and 75% of the direct NO/GO correspond to innovative synergies (Strane methodology).

Figure 7 – Final technical viability evaluation (GO and NO/GO)

The initial synergy identification (D3.1) define 39 innovative synergy types obtained by the Strane methodology, and 61 provided by other information sources (Figure 9).

Figure 8 – Synergies divided by identification source
Regarding Strane methodology, the results show that 26 out of 39 synergy types were evaluated as technically viable, corresponding to 66.7% success rate (Figure 10). The results on the technical synergy validation, demonstrate the reliability of the innovative methodology.

In a deeper analysis on the previous results, from the 26 synergies evaluated as GO, 65.3% correspond to indirect synergies while 34% correspond to direct ones. Among the ones identified as NO/GO, 53% correspond to direct ones and 47% to indirect. Indirect synergies presented higher technical positive evaluation rates.

Figure 11 present the results on the technical evaluation of synergy types obtained from other sources, only about 5 % of the synergies were considered as technically unfeasible. The conventional synergy identification methods present very high success rates on technology evaluation.

Considering the hypothetical procedure/technology technical characterization options (see section 2.2), the results achieved shown that 75% of the synergies type characterized were associated to full procedures and just 25% were associated to specific technologies. Within the technology associated synergies, 85% refers to indirect synergies and just 15% to direct ones. Regarding procedure associated synergies, 60% refers to direct and 40%
Deliverable 3.2

to indirect. These results reinforce the initial theoretical hypothesis that indirect synergy technical valorisation deal with higher technical specifications and consequently technology requirements.

During the technical characterization, some of the synergies initially defined as direct/indirect were suitable to be switched. Table 4 compile the synergies involved, their status and support comments. Three direct synergies could turn into indirect, while twelve indirect synergies could be considered as direct.

Table 4 – Resume table of synergies able to change initial Direct/Indirect status

<table>
<thead>
<tr>
<th>Synergy number</th>
<th>Initial Status</th>
<th>Possible Status</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Direct</td>
<td>Indirect</td>
<td>Optionally turned into indirect in order to improve its quality as a raw material for cement production.</td>
</tr>
<tr>
<td>65</td>
<td>Direct</td>
<td>Indirect</td>
<td>Associated to compulsory desulphurization process requirements.</td>
</tr>
<tr>
<td>22</td>
<td>Direct</td>
<td>Indirect</td>
<td>Compulsory indirect due to high demand of processing involved. Technology is not at optimum state of development.</td>
</tr>
<tr>
<td>5</td>
<td>Indirect</td>
<td>Direct</td>
<td>Waelz kiln technology is already implemented for secondary Zinc production. EAF Dust can be directly sent to this receiver.</td>
</tr>
<tr>
<td>9/10/39</td>
<td>Indirect</td>
<td>Direct</td>
<td>Sulphuric acid recovery is already a standard in this sender sector. Equipment to produce Sulphuric Acid is already available at this sender process.</td>
</tr>
<tr>
<td>31/32</td>
<td>Indirect</td>
<td>Direct</td>
<td>Processing of salt slag is already a standard in this sender process. Aluminium oxides separation is already implemented and can be directly sent to final users.</td>
</tr>
<tr>
<td>85</td>
<td>Indirect</td>
<td>Direct</td>
<td>Processing of wastewaters containing oil is already a standard technology in this sender process. Recovered oil can be directly sent to final users.</td>
</tr>
<tr>
<td>41</td>
<td>Indirect</td>
<td>Direct</td>
<td>Processing of ash is current practice in this sender sector.</td>
</tr>
<tr>
<td>59</td>
<td>Indirect</td>
<td>Direct</td>
<td>Processing of slag ash is current practice in this sender sector.</td>
</tr>
<tr>
<td>18</td>
<td>Indirect</td>
<td>Direct</td>
<td>Hydrogen is already a by-product of the sodium chlorate production and can be used as fuel or as a raw material for other processes.</td>
</tr>
<tr>
<td>19</td>
<td>Indirect</td>
<td>Direct</td>
<td>Processing of off-gases is already a standard in this sender process. If the proposed technology is already implemented at the sender process, then the Hydrogen is already a by-product and can be directly sent to final users.</td>
</tr>
<tr>
<td>94</td>
<td>Indirect</td>
<td>Direct</td>
<td>Steam can be used directly without any treatment or technology requirements.</td>
</tr>
</tbody>
</table>

Regarding the initial indirect synergies, necessary treatments/technologies for the valorisation or extraction of elements of interest, can be already part of the sender sector practices (sometimes associated to compulsory treatments), in those cases they can turn into direct ones. In case those technologies/equipment/procedure are not available (at sender, receiver or intermediary facilities) they will still be considered as indirect synergies.

Considering the final technical viability analysis of the synergies, availability and usability are used as evaluation criteria. In case of two positive results on availability and usability the final viability analysis is considered as GO. Even though, some GO exceptions occur with a single positive result. Indirect Synergy 63 for example, recovery of poultry dejections for tanning process, even it is not applicable at industrial Scale (it is still an emerging technology) it is technically viable for implementation.

Concerning the eight NO/GO direct synergies, five of them, related to ash and sludge recovery were technically reproved due to the lack of data on the mineralogical composition of by-products. The selection of technologies
and further technical viability analysis is highly dependent on those requirements. In case that reliable data can be obtained, synergy 27, 23, 15, 11 and 44 can be unlocked and turned into final GO.

Concerning the eight NO/GO indirect synergies, no procedure or technology was identified for synergy 76 and 77, as no studies were found concerning Alumina recovery from BOF slags. Half of NO/GO indirect synergies correspond to Steel sector as sender.

Synergies 91, 92, 93, 94, 95 and 96 present generic approaches on technical procedure and technologies characterization due to its multiple sender/receiver alternatives. There is a high valorisation potential due to its intersectoral applicability. The utilization of specific case studies and dedicated research sub-projects is advised to valorise them and allow better approaches and accuracy on the technical economic results.

As a final remark, during the individual research process radical approach changes were made into synergy 44 and 57. In direct synergy 44 the receiver process was changed from Primary Aluminium Casthouse to Primary Zinc production since there was no specific reference on the utilization of sand as a flux in the Aluminium subsector. In indirect Synergy 57 the initial element of interest, hydrochloric acid (HCl), was not found in the primary aluminium process from non-ferrous metals sector. Therefore, a new element of interest and a new process were defined for the same sender sector. The element of interest was changed to aluminium and the process was changed to secondary aluminium. Receiver sector and process were changed as well to Iron and Steel and basic oxygen steelmaking, respectively.

5. Guidelines for future TDB use and update

In addition to the actual objectives of task T3.3 presented in section 1, the TDB format presented compiles the main information necessary to be used as baseline study for further resource waste valorisation. The technical approaches presented per synergy types identify possible symbiotic exchanges that can be applied either directly or with some modifications to a wider range of intersectoral valorisation options. In this sense, the unexploited potential of the TDB is considerably high.

The existing excel format (presented in PDF in the report) allows the identification of existing synergy possibilities by simple filtration on dataset 1 variables shown in Table 6. It also allows industries, researchers, policy makers and other interested stakeholders to access, apart from all the intersectoral synergies available, the full set of technical and economic information associated with their possible implementation.

| Table 5 – Resume table of variables suitable for synergy/procedure technology identification |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| BY-PRODUCT | STATE OF MATTER | ELEMENT OF INTEREST | SENDER SECTOR AND PROCESS | RECEIVER SECTOR AND PROCESS |

Once the initial filtration is performed, all information concerning dataset 2 and dataset 3 is presented sequentially in the excel file.

Even though the current TDB excel file possesses basic functionalities, the database architecture and layout not only fulfils the objectives set for task T3.3 but also has the potential for further and future improvements, which can be made at different scales:

- A new or improved interface in Excel file
Deliverable 3.2

- New software for easier end user interface
- Connection with other industrial symbiosis databases
- Web application with dynamic research modules

In the current TDB format, upgrade of data can be easily done by inserting new data rows in the Excel template.

The update of the TDB can be made by following e.g. the following procedure:

- Identify a waste stream
- Characterise the composition of the whole flow at the receiver sector
- Use a matching algorithm/Strane methodology or other relevant IS tools to find a receiver industry type
- Identify all characteristics required for the flow at the receiver sector
- Search in BREF if a process which can deal with the flow is already integrated in the current process
- Productivity range pre-definition
- Which main source to identify a technology
- Which background is necessary to update the TDB

The template developed is prepared for upgrading on future research including alternative costs, inputs, outputs and the correspondent references.

6. Conclusions and perspectives

Strane methodology shown to be a very reliable methodology for the definition of new synergy types for intersectoral sectors. From the initial 39 Synergies almost 67 % were technically evaluated as GO.

The technical characterization accuracy is highly dependent on the existence of full procedure or single technology involved in the synergy. Technical assessments on multi process procedure is normally unavailable. Assumptions on those cases present high uncertain results.

Technical data on technology productivity and consumables is highly dependent on the scale used. Better approximations can be obtained by productivity range pre-definition.

Data collecting on the economic assessment variables is the biggest challenging process for quantitative evaluation. Data protection, dependence on technology scalability and variability on information sources were the biggest barriers found.

The different taxonomy used for processes, technologies and materials identification within different databases limits its wider utilization. This normalization process could increase data availability for technical characterization.

Concerning all data unavailable presented as N.F. in the TDB, the future acquisition by industry contact, database sharing and research projects can increase the accuracy of the results, better conclusions and continuous improvement of the TDB.

The direct valorisation of by-products (for example sludges) is highly dependent on their chemical/ mineralogical composition to fill specified requirements of the receiver sector and process. Due to the variation on those by-
product characteristics associated to raw materials used in sender process, technology /procedure identification are highly variable.

It is also important to note that despite a by-product being unsuitable for certain application, for instance, raw material for cement production, it could be suitable for other applications with lower quality requirements within the sector, for instance as aggregates for concrete production. Additionally, a by-product could also be suitable as a raw material for a specific manufacturing process, however, the final product quality is inferior and not suitable for the original application. Nonetheless, a new market for these products could be unfold.

Innovative synergies (Strane methodology) identified in D3.1 were the most challenging as no significant background was available.

Indirect Synergies analysis was in the technical perspective a more exhaustive research challenge due to the different amount of processes involved and correspondent characterizations required.

There is a huge potential for resource valorisation associated to the synergy type technically defined as NO/GO. At most of them, the resource is highly available, but technologies were not scaled, adapted or properly developed to valorise the resource. In some cases, there was also a lack of information regarding whether or not the valorisation of a by-product is possible as there are no precedents of its direct utilization on a specific receiver sector. In some of those cases information could be found regarding the same element of interest on the same type of by-product, albeit of different industrial processes, and there are general procedures/technologies that could be applied to a great variability of by-products (dusts, sludges, slags). In those cases, the final viability resume could indicate a GO.

Even some GO results shown that technologies are commercially available and used at some industrial sites, their implementation is still not widely spread. Incentives and barriers should be taken into consideration on the analysis to improve their scalability.

The actual TDB template and guidelines for use and update, intent to fill the gap found in terms of available tools to support industries, decision makers and researchers on the identification and mostly, the evaluation of the technical viability of IS processes.

The TDB developed present a huge potential for R&D+i mostly associated to the barriers identified during GO and NO/GO synergy type technical characterization. To overcome those barriers, further research is required including intersectoral demonstration projects between critical sectors, a huge opportunity for future work in this area.

The work presented can significantly contribute with relevant data to be included in further BREF updates, as well as considered as current Best Practices.

As final remark, the results presented in this deliverable will support the final evaluation on the most promising synergies at European level potential evaluation.
7. References

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Synergy 2

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Synergy 3

Synergy 4

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Synergy 5
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Synergy 6

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Synergy 7


Synergy 8


Synergy 9


Synergy 10


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Synergy 11

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Synergy 15


Synergy 16


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Deliverable 3.2

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Synergy 18

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Synergy 19

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JRC 2014 BREF Refining of Mineral Oil and Gas

Synergy 20


Synergy 21


JRC 2014 BREF Refining of Mineral Oil and Gas

Synergy 22


Synergy 23

JRC 2012 BREF Manufacture of Glass

Synergy 24

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Synergy 25


Synergy 26


Synergy 27

JRC 2016 BREF Non-ferrous Metals Industries

Synergy 28


Synergy 29


Synergy 30


Synergy 31


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Synergy 40

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Synergy 41


Synergy 42


Synergy 43


Synergy 44


Synergy 45


Synergy 46

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Synergy 47

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Synergy 53


Synergy 54


Synergy 55


Synergy 56


Synergy 57


Synergy 58


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Synergy 59

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Synergy 60


Synergy 61


Synergy 62


Synergy 63


Synergy 64 - NO REF

Synergy 65


Synergy 66


Synergy 67 - NO REF
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Synergy 68


Synergy 69


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Synergy 74


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Synergy 75


Synergy 76 - NO REF

Synergy 77 - NO REF

Synergy 78

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Synergy 79

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Synergy 80

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JRC 2018 BREF Waste Treatment

Synergy 81


Synergy 82

JRC 2017 BREF Large Combustion Plants

JRC 2014 BREF Production of Pulp, Paper and Board

JRC 2006 BREF Waste Incineration

Synergy 83


JRC 2017 BREF Large Combustion Plants
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Synergy 84


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Synergy 85

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Synergy 88


Synergy 89


Synergy 90 - NO REF

Synergy 91


Synergy 92

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