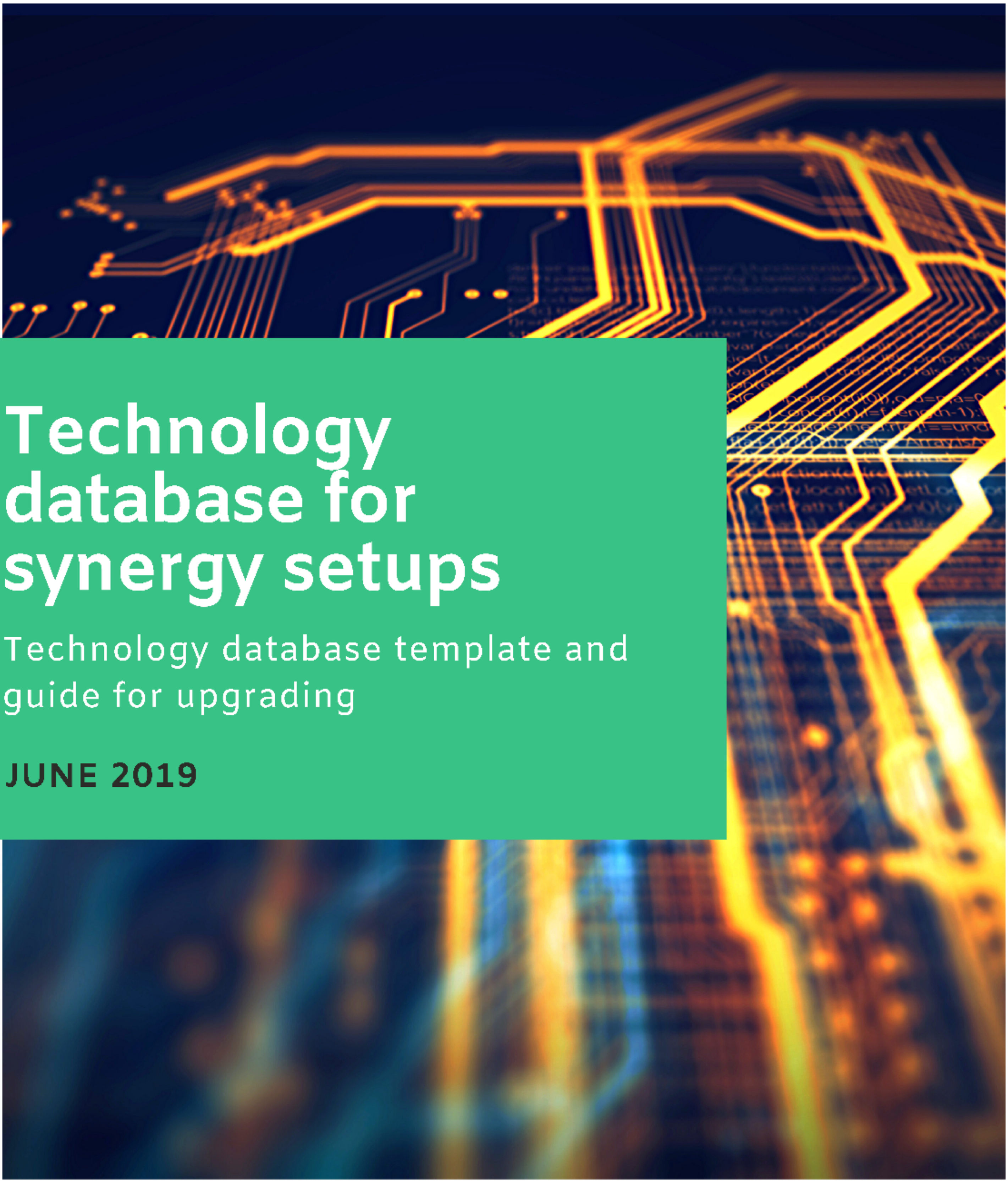

Technology database for synergy setups

Technology database template and guide for upgrading

JUNE 2019

SCALER

SCALING EUROPEAN RESOURCES WITH INDUSTRIAL SYMBIOSIS

Authors

Name: João Azevedo, Rui Dias, Inês Ferreira, Juan Henriques, Marco Estrela, Cristina Ascenço

Organisation: ISQ

Document history

VERSION	DATE	AUTHOR	DESCRIPTION
0.1	05/06/19	João Azevedo	Draft
0.2	12/06/19	Cristina Ascenço	Reviewed the report and provided contributions
0.3	16/06/19	João Azevedo	Incorporated contributions and finalised the deliverable

Internal review history

REVIEWED BY	DATE	DESCRIPTION
Jean-Baptiste Quintana (Strane)	21/06/19	Deliverable review
Marco Estrela	29/06/19	Integration of Strane's suggestions and final review

Document details

FILE NAME	VERSION
D3.2_SCALER_Technology Database template and guide for upgrading_v1.0.docx	1.0

OWNER	ORGANISATION
João Azevedo	ISQ

Table of contents

Contents

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.

List of Figures

List of Tables

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

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.

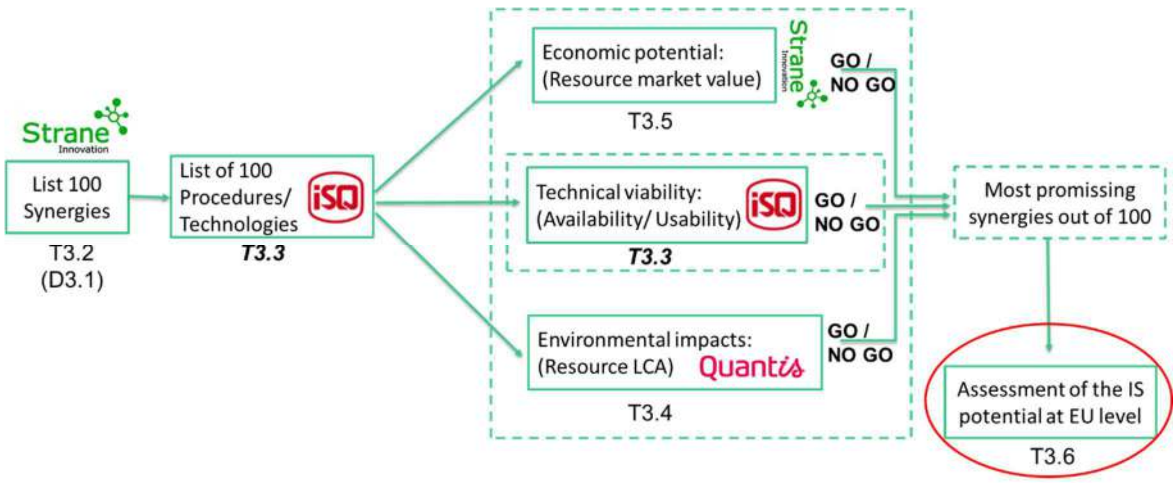

Figure 1 – Interdependences, inputs and outputs of T3.3 in WP3

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.

Table 1 - TDB Objectives and information of the datasets structure

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

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.

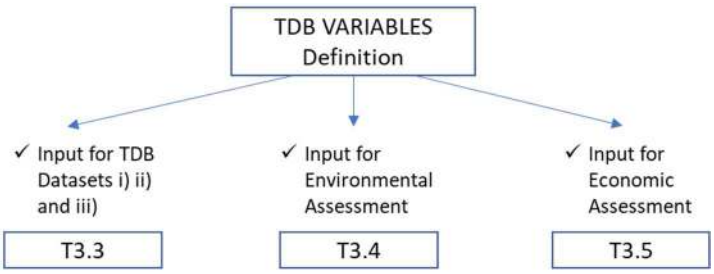

Figure 2 – TDB Variables definition scheme

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

	VARIABLE NAME	DATA SET	INFORMATION PROVIDED	QTT	QLT	INPUT INFO. SOURCE	END USER
Synergy characterization	SYNERGY ID NUMBER	1	Synergy ID	N.A(1)	N.A(1)	D 3.1	WP3
	BY-PRODUCT	1	by-product ID		X	D 3.1	WP3
	STATE OF MATTER	1	ID Physical State of the by-product		X	D 3.1	WP3
	ELEMENT OF INTEREST	1	Defines which is the valuable part to recover from by-product		X	D 3.1	WP3
	SENDER SECTOR AND PROCESS	1	Defines synergy sender sector and process		X	D 3.1	WP3
	RECEIVER SECTOR AND PROCESS	1	Defines synergy receiver sector and process		X	D 3.1	WP3
	TECHNICAL OBJECTIVE	1	Resumes the technical objective of the procedure or technology		X	D 3.1	WP3
	RESOURCE EXCHANGED	1	Defines if energy/water or materials were exchanged		X	D 3.1	WP3
	TYPE OF SYNERGY	1	Defines if the synergy is DIRECT/INDIRECT*		X	D 3.1	WP3
	IDENTIFICATION SOURCE	1	Describe the identification sources on synergy validation		X	D 3.1	WP3
Procedure and Technology general description	IDENTIFICATION	2	An equation resumes the various processes involved: Pre-treatment (PT), Technology (T) and Post treatment (POT)		X	Own methodology (2)	T3.4
	PROCEDURE (P) (Name and description)	2	Generic description of all processes involved from the by-product/waste stream until its final recovery/utilization use		X	BREF/papers/ technical brochures/books/other sources	T3.4
	TECHNOLOGY (T) (Name and description)	2	Describes if the technology/equipment that allows the valorisation process is applicable		X	BREF/papers/ technical brochures/books/other sources	T3.4
	POST TREATMENT (POT) (YES/N.A/NO and description)	2	In case a technology is used, it describes any treatment necessary post technology application. A initial YES/N.A/NO define need on Non Applicability		X	BREF/papers/ technical brochures/books/other sources	T3.4
	COMPLEMENTARY INFORMATION	2	Any other relevant information concerning P/T/POT interpretation		X	BREF/papers/ technical brochures/books/other sources	T3.4
	CHARACTERIZATION (Identification)	2	Identify if the following analysis correspond to the full procedure (P) or Technology (T) previous presented.		X	Own methodology	T3.4 ; T3.5 ; T3.6
	CHARACTERIZATION (Site/Ext Facility/receiver)	2	Identify where can the Procedure or Technology take place. Sender site, external intermediary facility or receiver site.		X	Own methodology	T3.4 ; T3.5 ; T3.6
	CHARACTERIZATION (Yield range)	2	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	X		BREF/papers/ technical brochures/books/other sources	T3.5 T3.6
	CHARACTERIZATION (Recovery rate)	2	Corresponds to the maximum amount of the element of interest/ by-product that can be valorised from the by-products/waste stream. All data obtained is referenced to the origin source	X		BREF/papers/ technical brochures/books/other sources	T3.5 T3.6
Transport	TRANSPORTAT (YES/NO/N.A.)	2	Identifies the needs or non-applicability on transport requirements		X	BREF/papers/ technical brochures/books/other sources	T3.4 ; T3.5 ; T3.6
	MEAN OF TRANSPORT	2	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.		X	BREF/papers/ technical brochures/books/other sources	T3.4 ; T3.5 ; T3.6
	DESCRIPTION	2	Describes specificities or approaches dealing with transportation		X	BREF/papers/ technical brochures/books/other sources	T3.4 ; T3.5 ; T3.6
Viability resume	AVAILABILITY - Commercially available	2	Identifies with a YES/NO result if the procedure/technology is commercially available. The result obtained is referenced to the origin source		X	BREF/papers/ technical brochures/books/other sources	T3.5 ; T3.6
	USABILITY – Industrial scale	2	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		X	BREF/papers/ technical brochures/books/other sources	T3.5 ; T3.6
	FINAL COMMENTS	2	Any other relevant information concerning previous viability analysis interpretation		X	BREF/papers/ technical brochures/books/other sources	T3.5 ; T3.6
Final conclusions	GO/NOGO (Technical viability)	2	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.		X	BREF/papers/ technical brochures/books/other sources	T3.6

	VARIABLE NAME	DATA SET	INFORMATION PROVIDED	QTT	QLT	INPUT INFO. SOURCE	END USER
Key costs	PROCEDURE/ TRANSPORT	3	Identifies the most relevant cost associated to the valorisation process to support decision making		X	Own methodology	T3.5; Industries
Procedure /Technology Inputs	REQUIRED SPECIFICATIONS	3	Refers to generic requirements of the technology or procedure. Can deal with by-products or other inputs		X	BREF/papers/ technical brochures/books/other sources	T3.4
	HEAT DEMAND	3	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.	X	X	BREF/papers/ technical brochures/books/other sources	T3.4
	ELECTRICITY DEMAND	3	Defines the electricity demand associated to the selected procedure/technology. The results presented are referenced to the origin source.	X	X	BREF/papers/ technical brochures/books/other sources	T3.4
	WATER DEMAND	3	Defines the water demand associated to the selected procedure/technology. The results presented are referenced to the origin source.	X	X	BREF/papers/ technical brochures/books/other sources	T3.4
	OTHER NECESSARY PRODUCTS	3	Defines the needs on any material/product required for the selected procedure/technology. The results presented are referenced to the origin source.		X	BREF/papers/ technical brochures/books/other sources	T3.4
Economic characterization	OPEX (Range)	3	Refers to the operational expenditure associated to the Procedure/technology operation. The results presented are referenced to the origin source.	X	X	BREF/papers/ technical brochures/books/other sources	T3.5; Industries
	CAPEX (Range)	3	Refers to the capital expenditure associated to the Procedure/technology implementation. The results presented are referenced to the origin source.	X	X	BREF/papers/ technical brochures/books/other sources	T3.5; Industries
	ROI/PBP/USEFULL LIFE	3	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.	X	X	BREF/papers/ technical brochures/books/other sources	T3.5; Industries
	COMMENTS	3	Any other relevant information concerning previous economic analysis interpretation		X	BREF/papers/ technical brochures/books/other sources	T3.5; Industries
Procedure /Technology Outputs	CO2 EMISSIONS	3	Refers to the emissions of CO2 associated to the procedure/ technology used	X	X	BREF/papers/ technical brochures/books/other sources	T3.4
	RESIDUES	3	Refers to the produced residues associated to the procedure/ technology used	X	X	BREF/papers/ technical brochures/books/other sources	T3.4
	OTHER RELEVANT PRODUCTS	3	Refers to any other products/by-products produced by procedure/ technology used	X	X	BREF/papers/ technical brochures/books/other sources	T3.4

(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.

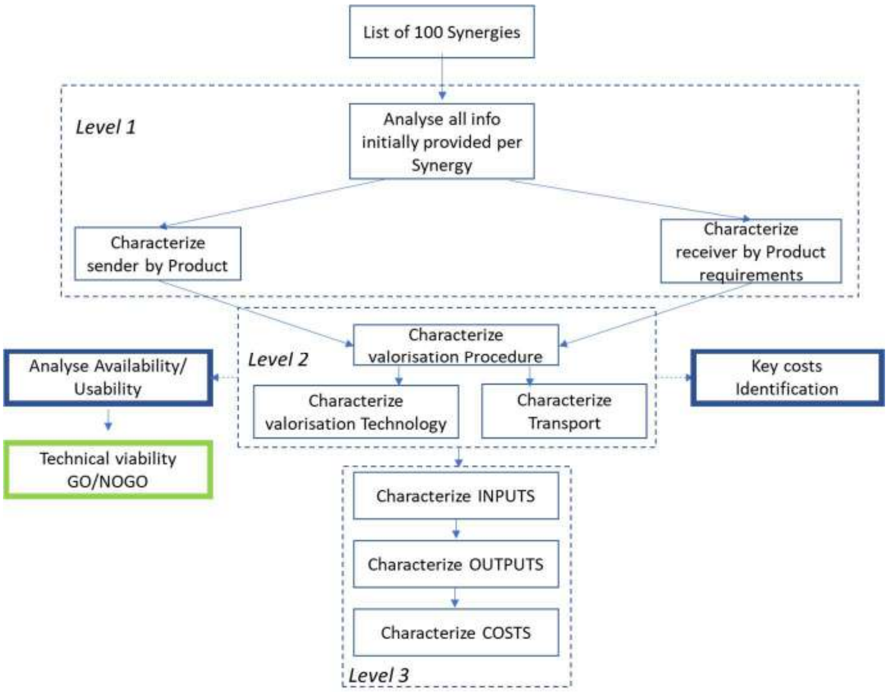

Figure 2 – General methodology for TDB data completion

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.

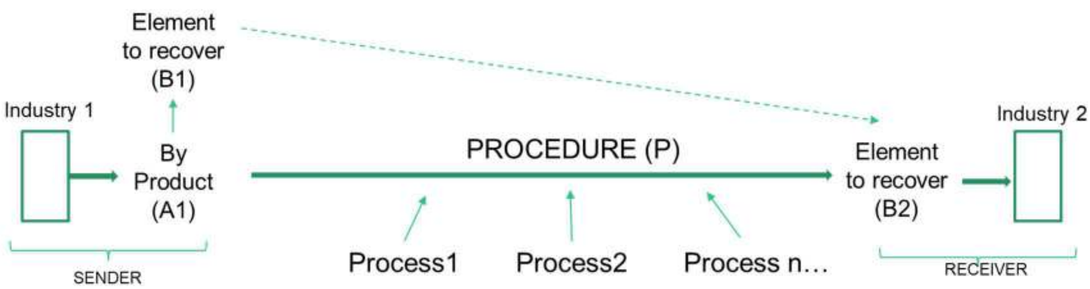

Figure 3 – Interpretation of indirect synergy types

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.

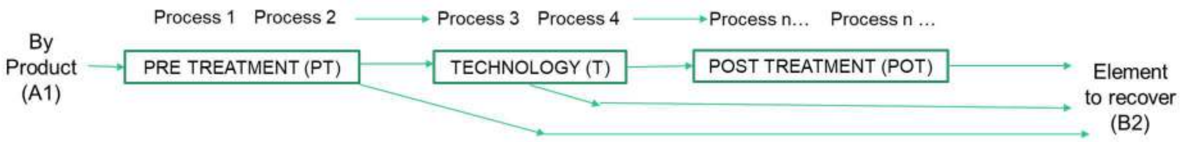

Figure 4 – Valorisation routes for Indirect Synergy types procedure stages

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.

Eq. 1 $$Procedure\ (P) = Pre\ Treatment\ (PT) + Technology\ (T) + Post\ Treatment\ (PT)$$

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.

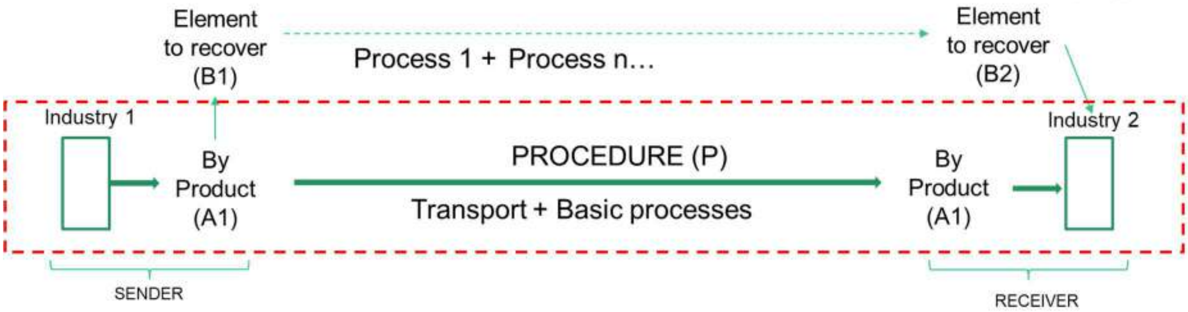

Figure 5 – Interpretation of direct synergy types

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.

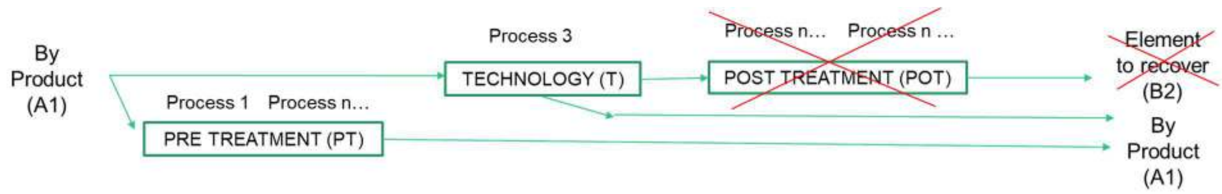

Figure 6 – Valorization routes for direct synergy procedure stages

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. $$Procedure\ (P) = Pre\ Treatment\ \boldsymbol{or}\ Technology\ (T)$$

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 3 - Resume table of Direct vs Indirect synergies type methodological analysis

Synergy Type	Main focus	Technical complexity	Procedure involved	Quantitative variables	Cost analysis	Clustering organization
Indirect	Element recovery	High	PT + T + POT	Yield / Recovery rates/ Heat/Electricity/Water	OPEX /CAPEX/ Transport	By sender sector
Direct	By-product Utilization	Low	P or T	Mostly N.A Recovery rates*	OPEX/CAPEX* Transport	By receiver sector

*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".

DATA SET 1: SYNERGY CHARACTERIZATION

SYNERGY

#	BY-PRODUCT	STATE OF MATTER	ELEMENT OF INTEREST	SENDER SECTOR AND PROCESS	RECEIVER SECTOR AND PROCESS	TECHNICAL OBJECTIVE	RESOURCE EXCHANGED ENERGY/ MATERIAL/ WATER	TYPE OF SYNERGY DIRECT/ INDIRECT	IDENTIFICATION SOURCE	PROCEDURE (P) = PRE TREATMENT (PT) + TECHNOLOGY TREATMENT (POT) P = PT + T + POT
1	COKE OVEN GAS	GAS	HYDROGEN	S : STEEL P : COKE OVEN PLANTS	S : REFINING MINERAL OIL AND GAS P : HYDROCRACKING PROCESS	The aim of this synergy is to recover coke oven gas from coke ovens and extract hydrogen to provide petrochemical industries.	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY BREF	P = PT+T
2	COKE OVEN GAS	GAS	METHANOL	S : STEEL P : COKE OVEN PLANTS	S : REFINING_MINERAL_OIL_AND_GAS P : ISOMERISATION_PROCESS	The aim of this synergy is to recover coke oven gas from coke ovens and extract hydrogen Methanol to provide petrochemical industries.	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY BREF	P = PT+T
5	EMISSIONS	SOLID-PART OF EMISSIONS	Zn	S : STEEL P : ELECTRIC ARC FURNACE STEELMAKING AND CASTING MANUFACTURING	S : NON FERROUS METALS INDUSTRIES P : ZINC PRODUCTION	The aim of this synergy is to recover steel sector zinc emissions from electrical arc furnace to provide non-ferrous metals industries zinc production.	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY	P
20	EMISSIONS	SOLID-PART OF EMISSIONS	Ni	S : STEEL P : BASIC OXYGEN STEELMAKING AND CASTING MANUFACTURING	S : NON FERROUS METALS INDUSTRIES P : NICKEL PRODUCTION	The aim of this synergy is to recover nickel from basic oxygen furnaces emissions to provide nickel and alloys production in non-ferrous metals industries.	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY	P = PT+T
37	EMISSIONS	SOLID-PART OF EMISSIONS	Zn	S : STEEL P : ELECTRIC ARC FURNACE STEELMAKING AND CASTING MANUFACTURING	S : NON FERROUS METALS INDUSTRIES P : LEAD AND TIN PRODUCTION	The aim of this synergy is to recover steel sector lead emissions from electrical arc furnace to provide non-ferrous metals industries lead production.	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY	P
43	SLUDGE	SOLID	NON FERROUS METALS & ORGANIC MATERIALS	S : STEEL P : SINTER PLANTS MANUFACTURING	S : NON FERROUS METALS INDUSTRIES P : SECONDARY COPPER SMELTING PYROMETALLURGICAL ROUTE	The aim of this synergy is to recover sludges from sinter plants to provide secondary copper smelting pyromatallurgical route.	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY BREF	P
46	SLUDGE	SOLID	NON FERROUS METALS & ORGANIC MATERIALS	S : STEEL P : SINTER PLANTS MANUFACTURING	S : NON FERROUS METALS INDUSTRIES P : LEAD AND TIN PRODUCTION	The aim of this synergy is to recover sludges from sinter plants to provide secondary copper smelting pyromatallurgical route.	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY BREF	P
76	BASIC OXYGEN FURNACE SLAG	SOLID	Al2O3	S : STEEL P : BASIC OXYGEN STEELMAKING AND CASTING MANUFACTURING	S : NON_FERROUS_METALS_INDUSTRIES P : ALUMINA_PRODUCTION	The aim of this synergy is to recover Al2O3 from basic oxygen furnaces slag to provide aluminium production	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY	N.A.
16	AIR EMISSIONS	GAS	H2SO4	S : STEEL P : COKE OVEN PLANTS	S : PRODUCTION OF PULP PAPER AND BOARD P : THE SULPHITE PULPING PROCESS	The aim of this synergy is to recover sulfuric acid from coke ovens emissions and provide sulphite pulping process.	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY	P = T
21	EMISSIONS	SOLID	SULPHUR	S : STEEL P : COKE OVEN PLANTS	S : PRODUCTION OF PULP PAPER AND BOARD P : THE SULPHITE PULPING PROCESS	The aim of this synergy is to sulphur from coke ovens emissions and provide sulphite pulping process.	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY	P = PT+T
77	BASIC OXYGEN FURNACE SLAG	SOLID	Al2O3	S : STEEL P : BASIC OXYGEN STEELMAKING AND CASTING MANUFACTURING	S : CERAMIC P : ELECTROPORCELAIN_MANUFACTURING	The aim of this synergy is to recover Al2O3 from basic oxygen furnaces slag to provide aluminium production	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY	N.A.
17	OFF_GAS	GAS	HYDROGEN	S : ORGANIC CHEMICALS P : STYRENE MANUFACTURING BY DEHYDROGENATION	S : REFINING MINERAL OIL AND GAS P : ISOMERISATION PROCESS	The aim of this synergy is to recover hydrogen from styrene manufacturing by dehydrogenation and provide isomerisation processes in refining industries.	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY BREF BEST PRACTICES	P=PT+T
19	PROCESS GASES	GAS	HYDROGEN	S : ORGANIC CHEMICALS P : STEAM CRACKING	S : REFINING MINERAL OIL AND GAS P : HYDRODESULPHURISATION PROCESS	The aim of this synergy is to recover hydrogen gas from steam cracking and provide hydrodesulphurisation processes in refining industries.	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY BREF BEST PRACTICES	P = PT+T
73	SPENT CATALYST METAL OXIDE	SOLID	Pt	S : ORGANIC CHEMICALS P : METAL OXIDE PROCESS	S : REFINING_MINERAL_OIL_AND_GAS P : CATALYTIC_CRACKING_FCC_PROCESS	The aim of this synergy is to recover Pt precious metals from metal oxide process and provide catalytic cracking FCC in refineries.	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY	P = T
3	PRIMARY LIQUID FUEL	LIQUID	ACETALDEHYDE DIETHYL ETHER ETHYL ACETATE ETHYL PROPIONATE	S : ORGANIC CHEMICALS P : ETHYL ACETATE PRODUCTION	S : CEMENT P : BURNING	The aim of this synergy is to recover waste fuels from ethyl acetate cleaning operation and send it to cement sector for clinker kiln combustible supply	COMBUSTIBLE	INDIRECT	INDUSTRIAL PARTNER SOURCE	P = T
71	ANODE SLIME	SOLID	Pd	S : NON FERROUS METALS INDUSTRIES P : PRIMARY COPPER SMELTING PYROMETALLURGICAL ROUTE	S : REFINING_MINERAL_OIL_AND_GAS P : CATALYTIC_CRACKING_FCC_PROCESS	The aim of this synergy is to recover Pd precious metals from primary copper smelting and provide catalytic cracking FCC in refineries.	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY BREF	P = T
74	ANODE SLIME	SOLID	Rh	S : NON FERROUS METALS INDUSTRIES P : PRIMARY COPPER SMELTING PYROMETALLURGICAL ROUTE	S : REFINING_MINERAL_OIL_AND_GAS P : CATALYTIC_CRACKING_FCC_PROCESS	The aim of this synergy is to recover Pd (Rh) precious metals from primary copper smelting and provide catalytic cracking FCC in refineries.	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY BREF	P = T
31	SALT SLAG	SOLID	ALUMINIUM OXIDES	S : NON FERROUS METALS INDUSTRIES P : SALT SLAG	S : CEMENT P : RAW MATERIALS PREPARATION	The aim of this synergy is to recover aluminium oxides from non ferrous metals salt slag process and provide cement sector for clinker raw material preparation.	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY BREF	P = PT+T
9	OFF-GAS	GAS	SULPHURIC ACID	S : NON FERROUS METALS INDUSTRIES P : PRIMARY COPPER SMELTING PYROMETALLURGICAL ROUTE	S : INORGANIC CHEMICALS P : SULPHATE PROCESS	The aim of this synergy is to recover sulphuric acid, as a by-product of copper primary smelting route, and provide sulphate process in inorganic chemical industries.	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY BREF	P = T
10	SULPHURIC ACID	LIQUID	SULPHURIC ACID	S : NON FERROUS METALS INDUSTRIES P : LEAD AND TIN PRODUCTION	S : INORGANIC CHEMICALS P : SULPHATE PROCESS	The aim of this synergy is to recover sulphuric acid, as a by-product of lead and tin process production in non-ferrous metals industries, and provide sulphate process in inorganic chemical industries.	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY BREF	P =T
39	SULPHURIC ACID	LIQUID	SULPHURIC ACID	S : NON FERROUS METALS INDUSTRIES P : LEAD AND TIN PRODUCTION	S : INORGANIC CHEMICALS P : PRECIPITATED SILICA AND SILICA GEL MANUFACTURING	The aim of this synergy is to recover sulphuric acid, as a by-product of lead and tin process production in non-ferrous metals industries, and provide sulphate process in inorganic chemical industries.	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY	P = T
38	COKE OVEN GAS	GAS	BENZENE	S : STEEL P : COKE OVEN PLANTS	S : ORGANIC CHEMICALS P : ETHYLBENZENE MANUFACTURING	The aim of this synergy is to recover benzene from coke ovens and provide ethylbenzene manufacturing.	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY	P = PT + T + POT
57	FILTER DUST	SOLID	ALUMINIUM	S : NON FERROUS METALS INDUSTRIES P : SECONDARY ALUMINIUM	S : IRON AND STEEL P : BASIC OXYGEN STEELMAKING	The aim of this synergy is to separate then recover acid and dust from filter dust, as a by-product of aluminium primary smelting route, and provide basic oxygen steelmaking route.	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY	P = T
58	ELECTROLYTE BLEED	LIQUID	ACID	S : NON FERROUS METALS INDUSTRIES P : SECONDARY COPPER SMELTING PYROMETALLURGICAL ROUTE	S : ORGANIC CHEMICALS P : PHENOL MANUFACTURING	The aim of this synergy is to separate then recover acid and nickel from electrolyte bleed, as a by-product of copper secondary smelting route, and provide phenol manufacturing.	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY	P = PT+T
52	ELECTROLYTE BLEED	LIQUID	ACID	S : NON FERROUS METALS INDUSTRIES P : PRIMARY COPPER SMELTING PYROMETALLURGICAL ROUTE	S : WASTE TREATMENTS INDUSTRIES P : PHYSICO CHEMICAL TREATMENTS	The aim of this synergy is to separate then recover acid and nickel from electrolyte bleed, as a by-product of copper primary smelting route, and provide waste treatments industries for physico chemimcal treatment.	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY BREF	P = PT+T
32	SALT SLAG	SOLID	ALUMINIUM OXIDES	S : NON FERROUS METALS INDUSTRIES P : SALT SLAG	S : GLASS P : STONE AND SLAG WOOL MANUFACTURING	The aim of this synergy is to recover aluminium oxides from non ferrous metals salt slag process and provide cement sector for clinker raw material preparation.	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY BREF	P = PT+T
41	ASHES	SOLID	ASHES	S : WASTE INCINERATION P : THERMAL TREATMENT H	S : NON FERROUS METALS INDUSTRIES P : SECONDARY COPPER SMELTING PYROMETALLURGICAL ROUTE	The aim of this synergy is to recover waste incineration ashes to provide secondary copper smelting pyromatallurgical route.	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY BREF	P = PT+T
59	SLAG ASH	SOLID	SLAG OR NON FERROUS METALS	S : WASTE INCINERATION P : THERMAL TREATMENT NH	S : NON FERROUS METALS INDUSTRIES P : SECONDARY COPPER SMELTING PYROMETALLURGICAL ROUTE	The aim of this synergy is to separate then recover slag ash from waste incineration thermat treatment and provide secondary copper smelting pyrometallurgical production.	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY	P = PT+T
51	SEMI-WET SORPTION RESIDUES	SOLID	LIME	S : WASTE INCINERATION P : FLUE GAS TREATMENT NH	S : STEEL P : SINTER PLANTS MANUFACTURING	The aim of this synergy is to recover lime from waste incieration flue gas treatment and provide sinter plants.	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY	P
33	BOTTOM ASH	SOLID	FERROUS-METALS	S : WASTE INCINERATION P : THERMAL TREATMENT H	S : STEEL P : PELLETISATION PLANTS MANUFAACTURING	The aim of this synergy is to recover waste incineration bottom ash to provide pelletisation plants in steel sector.	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY BREF	P=PT+T
42	SLUDGE	SOLID	NON FERROUS METALS & ORGANIC MATERIALS	S : REFINING MINERAL OIL AND GAS P : CRUDE ATMOSPHERIC DISTILLATION	S : NON FERROUS METALS INDUSTRIES P : SECONDARY COPPER SMELTING PYROMETALLURGICAL ROUTE	The aim of this synergy is to recover sludges from crude atmospheric distillation in refining industries to provide secondary copper smelting pyromatallurgical route.	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY	P = T
85	VISBREAKING WASTE WATER	LIQUID	OIL	S : REFINING_MINERAL_OIL_AND_GAS P : VISBREAKING_PROCECSS	S : NON_FERROUS_METALS_INDUSTRIES P : WAELZ_KILN_OPERATION	The aim of this synergy is to recover oil from visbreaking operation waste water and provide waelz kiln opearation in zinc and cadium industries.	COMBUSTIBLE	INDIRECT	STRANE METHODOLOGY BREF BEST PRACTICES	P = PT+T
53	WATER ELECTROPORCELAIN AFTER FLOCCULATION	SOLID- METAL PARTICLES IN WATER	Ni COBALT ALUMINIUM ZINC	S : REFINING MINERAL OIL AND GAS P : VACUUM DISTILLATION	S : FERTILISERS P : NPK FERTILISER PRODUCTION	The aim of this synergy is to recover non-ferrous metals from electroporcelain manufacturing waste water to provide nickel, cobalt and alloys production in non-ferrous metals industries.	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY	P =T
88	CRUDE ATMOSPHERIC DISTILLATION WASTE WATER	LIQUID	OIL	S : REFINING_MINERAL_OIL_AND_GAS P : CRUDE_ATMOSPHERIC_DISTILLATION	S : INORGANIC_CHEMICALS P : FURNACE_BLACK_PROCESS	The aim of this synergy is to recover oil from crude atmospheric distillation waste water and provide furnace black process in inorganic chemicals.	COMBUSTIBLE	INDIRECT	STRANE METHODOLOGY BREF BEST PRACTICES	P = T
81	CRUDE ATMOSPHERIC DISTILLATION WASTE WATER	LIQUID	OIL	S : REFINING_MINERAL_OIL_AND_GAS P : CRUDE_ATMOSPHERIC_DISTILLATION	S : STEEL P : BLAST_FURNACES_MANUFACTURING	The aim of this synergy is to recover oil from crude atmospheric distillation waste water and provide blast furnaces in steel industries.	COMBUSTIBLE	INDIRECT	STRANE METHODOLOGY BREF	P = T
54	VACUUM DISTILLATION WASTE WATER	LIQUID	NH3	S : REFINING MINERAL OIL AND GAS P : VACUUM DISTILLATION	S : FERTILISERS P : NPK FERTILISER PRODUCTION	The aim of this synergy is to recover amonia from vacuum distillation in refining industries to provide NPK fertilisers production.	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY	P = T
55	GAS SEPARATION WASTE WATER	LIQUID	NH3	S : REFINING MINERAL OIL AND GAS P : GAS SEPARATION PROCESSES	S : FERTILISERS P : UREA PRODUCTION	The aim of this synergy is to recover amonia from vacuum distillation in refining industries to provide NPK fertilisers production.	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY	P = T
45	SLUDGE	SOLID	NON FERROUS METALS & CHROMIUM	S : INORGANIC CHEMICALS P : SODIUM CHLORATE PRODUCTION	S : NON FERROUS METALS INDUSTRIES P : LEAD AND TIN PRODUCTION	The aim of this synergy is to recover sludges from sodium chlorate process and provide and lead and tin production.	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY	P
18	EMISSIONS	GAS	HYDROGEN	S : INORGANIC CHEMICALS P : SODIUM CHLORATE PRODUCTION	S : REFINING MINERAL OIL AND GAS P : HYDROCRACKING PROCESS	The aim of this synergy is to recover hydrogen from sodium chlorate production in inorganic chemicals industries and provide hydrocraking processes in refining industries.	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY BREF BEST PRACTICES	P
70	ACID	GAS	HCl	S : INORGANIC_CHEMICALS P : UNDEFINED	S : COMBUSTION_PLANT P : INTEGRATED_GASIFICATION_COMBINED_CYCLE	The aim of this synergy is to recover HCl from basic chemical industries and provide power plants.	MATERIAL EXCHANGE	INDIRECT	BEST PRACTICES	P = T
56	WATER ELECTROPORCELAIN AFTER FLOCCULATION	SOLID- METAL PARTICLES IN WATER	Zn	S : CERAMIC P : ELECTROPORCELAIN MANUFACTURING	S : NON FERROUS METALS INDUSTRIES P : LEAD AND TIN PRODUCTION	The aim of this synergy is to recover non-ferrous metals from electroporcelain manufacturing waste water to provide nickel, cobalt, aluminium, zinc and alloys production in non-ferrous metals industries.	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY	P = T
75	EMISSIONS	SOLID - PART OF EMISSIONS	Sb	S : LIME P : LIME MANUFACTURING MIXED FEED SHAFT KILN	S : NON_FERROUS_METALS_INDUSTRIES P : SECONDARY_COPPER_SMELTING_PYROMETALLURGICAL_ROUTE	The aim of this synergy is to recover Sb precious metals from lime mixed feed shaft kiln and provide non-ferrous metals industries.	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY	P = T
61	WASTE PLASTICS (AMP)	SOLID	WASTE PLASTICS (AMP)	S : ENGINEERING P : PLASTIC PART MANUFACTURING	S : ENGINEERING P : BLAST MEDIA PRODUCTION	The aim of this synergy is to send waste plastics (AMP) from automotive industries to plastic manufacturers.	MATERIAL EXCHANGE	INDIRECT	BEST PRACTICES	P = PT+T
62	YEAST SLUDGE AND SLURRY	SOLID	YEAST NUTRIENTS	S : PHARMACEUTICAL P : FERMENTATION PROCESS	S : AGRO-INDUSTRIAL PRODUCTION P : LIVESTOCK FEEDING	The aim of this synergy is to recover yeast slurry from pharmaceuticals plants and provide food for animal farming.	MATERIAL EXCHANGE	INDIRECT	BEST PRACTICES	P = PT+T
63	POULTRY DEJECTIONS	SOLID	EXTRACELLULAR ENZYMES	S : AGRO-INDUSTRIAL PRODUCTION P : INTENSIVE_POULTRY_FARMING	S : TEXTILE P : TANNING	The aim of this synergy is to recover poultry dejections to perform taning phase in textile industries.	MATERIAL EXCHANGE	INDIRECT	BEST PRACTICES	P = PT+T
72	GREEN LIQUOR SLUDGE	SOLID	Cr	S : PRODUCTION OF PULP PAPER AND BOARD P : THE KRAFT PULPING PROCESS	S : STEEL P : ELECTRIC_ARC_FURNACE_STEELMAKING_AND_CASTING_MANUFACTURING	The aim of this synergy is to recover lime from kraft pulping process in pulp and paper production sector, and provide electrical arc furnaces for steel manufacturing.	MATERIAL EXCHANGE	INDIRECT	STRANE METHODOLOGY	P = T

95	SOLID WASTE FUEL FEEDSTOCK	VARIOUS STATE OF MATTER	Various waste - See table n°	S : DIFFERENT: SEE ANNEXED TABLES (D 3.1) P : DIFFERENT: SEE ANNEXED TABLES (D 3.1)	S : WASTE TREATMENTS INDUSTRIES P : WASTE TREATMENT AIMED PRODUCE MATERIAL USED AS FUEL	The purpose of this synergy is to recover all types of solid combustible waste and send it to waste treatment industries to produce conventional fuels.	WASTE FOR FUEL PREPARATION	INDIRECT	STRANE METHODOLOGY	P = PT+T	Mechanical treatment of Waste with calorific Value	[illegible]	[illegible]	[illegible]	N.A	After the final processing step, a solid waste fuel is obtained. In some cases, additional processing steps may be required to design the solid waste fuel according to the consumers' wishes. For example, further compacting or size reduction may be requested. Once the combustible material has been separated, it is then shredded and either sent to the customer, or pelletised before it is sent for combustion (this usually occurs when the material is burnt off site, as a densified fuel reduces transport costs).	Solid waste can be a heterogeneous mixture of materials. The aim is to homogenize a combustible material out of non-hazardous solid waste by appropiate preparation technologies. The process to derive fuel from solid wastes separates the calorific fraction and the non-calorific fraction contained in the waste input. The quality assurance of the preparation of waste to be used as fuel is driven by the need to meet the specifications set by the receiving facility. This is related to the waste composition characterisation (see Section 2.3.2.2 BREF WT), and to the output quality management system (see Section 2.3.2.6 BREF WT). Mixing and blending (see Section 2.3.2.8 BREF WT).	**P**	Receiver (Waste treatment facility)	N.F.	The recovery rates are dependent on the % of calorific value materials available in the mixed waste residues to separate . Mechanical separation do not induce significant losses on calorific value recovered wastes.	BREF *WT*	YES	Road; Railroad	The actual transportation networks used for waste management (e.g MSW) are fully suitable for solid waste valorization transportation.	YES
96	LIQUID WASTE FUEL FEEDSTOCK	VARIOUS STATE OF MATTER	Various waste - See table n°	S : DIFFERENT: SEE ANNEXED TABLES (D 3.1) P : DIFFERENT: SEE ANNEXED TABLES (D 3.1)	S : WASTE TREATMENTS INDUSTRIES P : WASTE TREATMENT AIMED PRODUCE MATERIAL USED AS FUEL	The purpose of this synergy is to recover all types of liquid combustible waste and send it to waste treatment industries to produce conventional fuels.	WASTE FOR FUEL PREPARATION	INDIRECT	STRANE METHODOLOGY	P = PT+T	Mechanical and physico-chemical preparation of hazardous liquid waste fuels	[illegible]	[illegible]	[illegible]	N.A.	Some liquid waste fuels can be prepared by blending different wastes that have high calorific values and feed them independently into the combustion chamber or they can be mixed/blended with conventional fuels (e.g. waste oil and fuel oils). Some liquid wastes, for instance oils, normally need pretreatment to remove bottoms, sediments, and water. This may be achieved through separation and dehydration.	The preparation of different types of waste fuel needs to consider the technical characteristics of the combustion plant/process using it (e.g. cement plant, lime plant, power plant (hard coal, lignite), specialised waste fuel combustion). These combustion processes have different technical characteristics Some factors affecting the extent to which the waste treatment operations depend on the waste fuel application are: type of waste used to prepare the waste fuel, techniques used for waste fuel storage; kind of furnace feeding (bulk material, blow feeding); fuel mix used in the combustion process; type of combustion process, grate firing, pyrolysis or fluidised bed specification of the process using the waste fuel in terms of composition: e.g. chlorine content for waste used in cement production. (BREF WT)	P	Receiver (Waste treatment facility)	N.A	Fuel yield is less than 100% of the waste quantity because of the water, ash and other impurities that may be cleaned and separated in the different proceses	BREF *WT*	YES	Road; Railroad	Dispatching to the customer is carried out by a truck loading station. This loading station is fed by the storage unit. BREF WT.	YES
91	HEAT	GAS	HEAT	S : DIFFERENT: SEE ANNEXED TABLES (D 3.1) P : DIFFERENT: SEE ANNEXED TABLES (D 3.1)	S : DIFFERENT: SEE ANNEXED TABLES (D 3.1) P : DIFFERENT: SEE ANNEXED TABLES (D 3.1)	The aim of this synergy is to recover heat and directly reuse it in nearby other industrial sites or for urban heating.	HEAT/STEAM RECOVERY	INDIRECT	STRANE METHODOLOGY BEST PRACTICES	P = PT+T	Waste heat recovery (WHR)	[illegible]	[illegible]	[illegible]	N.A.	Waste heat recovery methods include capturing and transferring the waste heat from a process with a gas or liquid back to the system as na extra energy source. Once waste heat is recovered no complementary treatament post utilization is required. In the case of significant heat is still generated, new WHR can be applied.	There are 3 main temperature ranges to consider on WHR processes. High temperature WHR consists of recovering waste heat at temperatures greater than 400 °C, the medium temperature range is 100–400 °C and the low temperature range is for temperatures less than 100 °C . Usually most of the waste heat in the high temperature range comes from direct combustion processes, in the medium range from the exhaust of combustion units and in the low temperature range from parts, products and the equipment of process units . The higher the temperature, the higher the quality of the waste heat and the easier optimisation of the waste heat recovery process	P	Site	N.F.	Highly dependent on Technology used. For high temperature boilers recovery rates between 40 and 90% can be recovered.	https://www.sciencedirect.com/science/article/pii/S2451904918300015	YES	High thermal isolated pipes and pumping system.	Transport technology is the same used in conventional heat transport system at industrial sites and district heating installations.	Highly dependent on technology. Table 1 (H. Jouhara et al) shows a summary of all the technologies presented including their temperature range, benefits and limitations. Individual analysis is adviced depending on the context.
92	HEAT	GAS	HEAT	S : DIFFERENT: SEE ANNEXED TABLES (D 3.1) P : DIFFERENT: SEE ANNEXED TABLES (D 3.1)	S : DIFFERENT: SEE ANNEXED TABLES (D 3.1) P : DIFFERENT: SEE ANNEXED TABLES (D 3.1)	The aim of this synergy is to recover heat for electricity producing	HEAT/STEAM RECOVERY	INDIRECT	STRANE METHODOLOGY BEST PRACTICES	P = PT+T	Thermodynamic cycles and Direct electrical conversion devices	[illegible]	[illegible]	[illegible]	N.A.	*Thermodynamic cycles:* Once waste heat is recovered to generate superheated steam no complementary treatment post utilization is required. After condensation of the steam the liquid can be recirculated and use waste heat again to restart the process. *Direct electrical conversion devices:* No treatments associated are required after heat recover and energy generation by direct electrical conversion devices	*Thermodynamic cycles:* Generally consists on a pump, a condenser, a evaporator and a generator. This is considered a multitechnology process. *Direct electrical conversion devices:* Based on different physical principals, are still emerging technologies with hogh potential utilization.	P	Site/ Ext. facility/ Receiver	N.A	*Thermodynamic cycles:* Highly dependent on the technology used. For rankine cycles an average of 20 to 40% of heat waste can be converted into electricity in medium- low temperatures grades. Organic Rankine Cycle: net efficiency of almost 22% can be achieved. Kalina cycle offers a better result when the recovered heat is of medium-high grade nature. *Direct electrical conversion devices:* Thermoelectric generation : efficiencies of 15%; Thermo photo voltaic (TPV) generator : efficiencies of 20% .	https://www.sciencedirect.com/science/article/pii/S2451904918300015	YES	High thermal isolated pipes and pumping system. (Considered as BAT)	For thermodinamic cycles, transport technology for waste heat is the same used in conventional heat transport system at industrial sites. Distance is the key factor for transport viability evaluation.	YES (Thermodynamic cycles) NO (Direct electrical conversion devices:)
93	STEAM	GAS	STEAM	S : DIFFERENT: SEE ANNEXED TABLES (D 3.1) P : DIFFERENT: SEE ANNEXED TABLES (D 3.1)	S : DIFFERENT: SEE ANNEXED TABLES (D 3.1) P : DIFFERENT: SEE ANNEXED TABLES (D 3.1)	The aim of this synergy is to recover steam and produce electricity	HEAT/STEAM RECOVERY	INDIRECT	STRANE METHODOLOGY BEST PRACTICES	P = PT+T	Electricity production by steam recovery.	[illegible]	[illegible]	[illegible]	N.A.	Once waste steam is turbined to generate electricity no complementary treatment post utilization is required. After condensation of the steam the liquid can be recirculated and use waste heat again to restart the process (ORC or KC), in the case of direct utilization in the turbine the remaining heat after condensation and pumpimg can be neglected or valorized for other thermal purposes.	The direct utilization of steam for electricity production is so highly dependent on its pressure, temperature and its chemical composition. This criteria will define the most appropriate procedure for its utilization. As an example, steam pressure between 4-5 bar are considered low pressure steam but it can be still valorized for energy production in low pressure turbines (temperature will signicantly influence the final technology selected). Pressure below 4 bar and low temperatures will require a pre heating system to reduce the moisture content an increase temperature before the turbine.	P	Site/ Ext. facility/ Receiver	N.A	For rankine cycles an average of 20 to 40% of heat waste can be converted into electricity in medium- low temperatures grades. Organic Rankine Cycle: net efficiency of almost 22% can be achieved. Kalina cycle offers a better result when the recovered heat is of medium-high grade nature. The valorization rates will be dependent on its temperature and pressure, chemical quality and the transport distance.	https://www.sciencedirect.com/science/article/pii/S2451904918300015	YES	High thermal isolated pipes and pumping system. (Considered as BAT)	The piping should be properly sized, supported, insulated, and configured with adequate flexibility. Pressure-regulating devices such as pressure-reducing valves and backpressure turbines should be configured to provide a proper steam balance among the different steam headers. Additionally, the distribution system should be configured to allow adequate condensate drainage, which requires adequate drip leg capacity and proper steam trap selection. BREF ENE	YES
94	STEAM	GAS	STEAM	S : DIFFERENT: SEE ANNEXED TABLES (D 3.1) P : DIFFERENT: SEE ANNEXED TABLES (D 3.1)	S : DIFFERENT: SEE ANNEXED TABLES (D 3.1) P : DIFFERENT: SEE ANNEXED TABLES (D 3.1)	The aim of this synergy is to recover steam and directly reuse it in nearby other industrial sites.	HEAT/STEAM RECOVERY	INDIRECT	STRANE METHODOLOGY BEST PRACTICES	P = PT+T	Steam distribution	[illegible]	[illegible]	[illegible]	N.C	Due to the high operating pressure values in steam systems, safety is an extremely important aspect in steam processes. Measures will deal with pressurized distributions networks. BREF ENE	Two main steam sources can be distributed: High pressure steam and Low pressure steam. The design of the distribution network will be so higly dependent on it. Distribution Higher pressure steam has the following advantages: the saturated steam has a higher temperature; the volume is smaller, which means the distribution pipes required are smaller; it is possible to distribute the steam at high pressure and to reduce its pressure prior to application. The steam thus becomes dryer and reliability is higher. 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 relatively smaller; leakage losses in the pipe system are lower; there is a decrease in scale build-up.. (BREF ENE)	P	Site/ Ext. facility/ Receiver	N.A	The valorization rates of surplus steam will depend on its temperature and pressure, the distribution technology used and the transport distance .	BREF ENE	YES	High thermal isolated pipes and pumping system. (Considered as BAT)	The piping should be properly sized, supported, insulated, and configured with adequate flexibility. Pressure-regulating devices such as pressure-reducing valves and backpressure turbines should be configured to provide a proper steam balance among the different steam headers. Additionally, the distribution system should be configured to allow adequate condensate drainage, which requires adequate drip leg capacity and proper steam trap selection. BREF ENE	YES

DATA SET 1: SYNERGY CHARACTERIZATION

ID NUMBER #	SYNERGY BY-PRODUCT	STATE OF MATTER	ELEMENT OF INTEREST	SENDER SECTOR AND PROCESS	RECEIVER SECTOR AND PROCESS	TECHNICAL OBJECTIVE	TECHNICAL OBJECTIVE #	RESOURCE EXCHANGED ENERGY/ MATERIAL/ WATER	TYPE OF SYNERGY DIRECT/ INDIRECT	IDENTIFICATION SOURCE
6	BASIC OXYGEN FURNACE SLAG	SOLID	SILICIUM ALUMINIUM CALCIUM IRON	S : STEEL P : BASIC OXYGEN STEELMAKING AND CASTING MANUFACTURING	S : CEMENT P : RAW MATERIALS PREPARATION	Recover and transport BOF slag as a silicium alumina and calcium supply	The aim of this synergy is to recover basic oxygen furnace slag and provide silicium, clacium and alumina for clinker raw material preparation and grinding cement mill.	MATERIAL EXCHANGE	DIRECT	STRANE METHODOLOGY BREF BEST PRACTICES
27	SLUDGE	SOLID	CALCIUM ALUMINIUM	S : STEEL P : SINTER PLANTS MANUFACTURING	S : CEMENT P : RAW MATERIALS PREPARATION	Sludge recovery for calcium and aluminium supply	The aim of this synergy is to recover calcium and aluminium from sinter plants sludges to provide cement raw material preparation.	MATERIAL EXCHANGE	DIRECT	STRANE METHODOLOGY
30	SLAG	SOLID	SILICIUM ALUMINIUM CALCIUM	S : STEEL P : BLAST FURNACES MANUFACTURING	S : CEMENT P : RAW MATERIALS PREPARATION	**Recover and transport** blast furnace **slag** as a silicium alumina and calcium supply	The aim of this synergy is to recover blast furnace slag to provide silicium alumina and calcium supply to cement sector for clinker raw material preparation.	MATERIAL EXCHANGE	DIRECT	STRANE METHODOLOGY BREF BEST PRACTICES
35	EAF SLAG	SOLID	SILICIUM ALUMINIUM CALCIUM	S : STEEL P : ELECTRIC ARC FURNACE STEELMAKING AND CASTING MANUFACTURING	S : CEMENT P : GRINDDING CEMENT MILL	**Recover and transport** EF **slag** as a silicium alumina and calcium supply	The aim of this synergy is to recover and transport EAF slag to provide a silicium alumina and calcium supply to grinding cement mill.	MATERIAL EXCHANGE	DIRECT	STRANE METHODOLOGY BREF BEST PRACTICES
7	GYPSUM	SOLID	GYPSUM	S : INORGANIC CHEMICALS P : SULPHATE PROCESS	S : CEMENT P : GRINDDING CEMENT MILL	Recover Gyspum from sulphate process and treat it to be compliant with standard gyspum used in grinding cement mill. A technology is required for red gypsum.	The aim of this synergy is to recover gypsum as an inorganic chemical solid waste from sulphate process to provide grinding cement mill in cement sector	MATERIAL EXCHANGE	DIRECT / INDIRECT FOR RED GYPSUM	STRANE METHODOLOGY BREF
8	GYPSUM	SOLID	GYPSUM	S : COMBUSTION PLANT P : COAL COMBUSTION	S : CEMENT P : GRINDDING CEMENT MILL	Recover Gyspum from coal combustion process process and treat it to be compliant with standard gyspum used in grinding cement mill	The aim of this synergy is to recover gypsum as an combustion plant solid waste from coal combustion to provide grinding cement mill in cement sector	MATERIAL EXCHANGE	DIRECT	STRANE METHODOLOGY BREF
50	LIMESTONE FINES	SOLID - PART OF EMISSIONS	LIMESTONE FINES	S : INORGANIC CHEMICALS P : SOLVAY PROCESS	S : CEMENT P : RAW MATERIALS PREPARATION	Recover limestone of limestone fines	The aim of this synergy is to recover limestone fines from solvay process to provide raw material preparation in cement industries.	MATERIAL EXCHANGE	DIRECT	STRANE METHODOLOGY BREF
25	LIME	SOLID	CALCIUM	S : FOOD DRINK AND MILK INDUSTRIES P : SUGAR BEET	S : CEMENT P : RAW MATERIALS PREPARATION	Lime recovery for calcium supply	The aim of this synergy is to recover lime from sugar beet production process to provide cement raw material preparation.	MATERIAL EXCHANGE	DIRECT	STRANE METHODOLOGY BREF
26	LIME	SOLID	CALCIUM	S : PRODUCTION OF PULP PAPER AND BOARD P : THE KRAFT PULPING PROCESS	S : CEMENT P : RAW MATERIALS PREPARATION	Lime recovery for calcium supply	The aim of this synergy is to recover lime from kraft pulping process in pulp and paper production sector to provide cement raw material preparation.	MATERIAL EXCHANGE	DIRECT	STRANE METHODOLOGY BREF
28	SAND	SOLID	SAND	S : FOOD DRINK AND MILK INDUSTRIES P : STRACH	S : CEMENT P : RAW MATERIALS PREPARATION	Sand recovery	The aim of this synergy is to recover sand from food and drink industries and provide cement sector raw material preparation.	MATERIAL EXCHANGE	DIRECT	STRANE METHODOLOGY BREF
29	RED MUD	SOLID	IRON	S : NON FERROUS METALS INDUSTRIES P : ALUMINA PRODUCTION	S : CEMENT P : RAW MATERIALS PREPARATION	Red mud recovery for Fe supply	The aim of this synergy is to recover red mud, as a by-product of alumina production, and provide cement sector for clinker raw material preparation.	MATERIAL EXCHANGE	DIRECT	STRANE METHODOLOGY BREF
79	TAR	LIQUID	TAR	S : ORGANIC_CHEMICALS P : STYRENE_MANUFACTURING_BY_DEHYDROGENATION	S : CEMENT P : BURNING	Recover tar for burning	The aim of this synergy is to recover tars from styrene manufacturing by dehydrogenation and provide cement and clinker kiln for burning.	COMBUSTIBLE	DIRECT	STRANE METHODOLOGY BREF
80	SPENT SOLVENTS	LIQUID	SPENT_SOLVENTS	S : ORGANIC_CHEMICALS P : STYRENE_MANUFACTURING_BY_HYDROGENATION	S : CEMENT P : BURNING	Recover spent solvent for burning	The aim of this synergy is to recover spent solvents from styrene production and provide cement and clinker kiln for burning.	COMBUSTIBLE	DIRECT	STRANE METHODOLOGY BREF
86	CARCASE	SOLID	CARCASE	S : SLAUGHTERHOUSES_AND_ANIMAL_BY_PRODUCTS_INDUSTRIES P : POULTRY_SLAUGHTER_PROCESS	S : CEMENT P : BURNING	Recover and transport carcasse to cement plants	The aim of this synergy is to recover carcasse from slaughterhouses and provide burning operation in cement industries. This synergy refers to poultry carcase valorisation but can be applied for others animals carcases.	COMBUSTIBLE	DIRECT	STRANE METHODOLOGY BREF BEST PRACTICES
4	COKE RESIDUES	SOLID	COKE	S : ORGANIC CHEMICALS P : STEAM CRACKING	S : STEEL P : SINTER PLANTS MANUFACTURING	Recover pure coke	The aim of this synergy is to recover pure coke from steam crackers cleaning flows and provide sinter plants in steel sector.	MATERIAL EXCHANGE	DIRECT	INDUSTRIAL PARTNER SOURCE
14	COKE	SOLID	COKE	S : ORGANIC CHEMICALS P : VYNIL CHLORIDE MONOMER MANUFACTURING	S : STEEL P : BLAST FURNACES MANUFACTURING	Recover pure coke or recover coke residues	The aim of this synergy is to recover coke from vynil chloride monomer manufacturing and provide blast furnace in steel industries.	MATERIAL EXCHANGE	DIRECT	STRANE METHODOLOGY
15	LIME	SOLID	LIME	S : PRODUCTION OF PULP PAPER AND BOARD P : THE KRAFT PULPING PROCESS	S : STEEL P : ELECTRIC ARC FURNACE STEELMAKING AND CASTING MANUFACTURING	Recover lime from kraft pulping process and treat it to be compliant with standard lime used in electrcal arc furnace	The aim of this synergy is to recover lime from kraft pulping process in pulp and paper production sector, and provide electrical arc furnaces for steel manufacturing.	MATERIAL EXCHANGE	DIRECT	STRANE METHODOLOGY
34	BOTTOM ASH	SOLID	FERROUS-METALS	S : COMBUSTION PLANT P : COAL COMBUSTION	S : STEEL P : PELLETISATION PLANTS MANUFAACTURING	Recover bottom ash and use it as a ferrous metals source	The aim of this synergy is to recover waste incineration bottom ash to provide pelletisation plants in steel sector.	MATERIAL EXCHANGE	DIRECT	STRANE METHODOLOGY BREF
11	LIME	SOLID	LIME	S : FOOD DRINK AND MILK INDUSTRIES P : SUGAR BEET	S : INORGANIC CHEMICALS P : CALCIUM CARBIDE MANUFACTURING	Recover lime from sugar production process and treat it to be compliant with standard lime used in clacium carbide production.	The aim of this synergy is to recover lime used as cleaning element in sugar production from beet in food and milk industries, and provide inorganic chemical industries which produce calcium carbide.	MATERIAL EXCHANGE	DIRECT	STRANE METHODOLOGY BREF
12	SALT	SOLID	SALT	S : NON FERROUS METALS INDUSTRIES P : SALT SLAG	S : INORGANIC CHEMICALS P : SODIUM CHLORATE PRODUCTION	Recover salt from salt slag and treat it to be compliant with standard salt required for sodium chlorate production	The aim of this synergy is to recover salt from non ferrous metals salt slag and provide inorganic chemical industries which produce sodium chlorate	MATERIAL EXCHANGE	DIRECT	STRANE METHODOLOGY BREF
13	SALT	SOLID	SALT	S : SLAUGHTERHOUSES AND ANIMAL BY PRODUCTS INDUSTRIES P : SHEEP SLAUGHTER PROCESS	S : INORGANIC CHEMICALS P : SODIUM CHLORATE PRODUCTION	Recover salt from sheep slaughterhouses and treat it to be compliant with standard slat required for sodium chlorate production	The aim of this synergy is to recover salt from sheep slaughter process in slaghterhouses and animal by products industries to provide inorganic chemical industries which produce sodium chlorate.	MATERIAL EXCHANGE	DIRECT	STRANE METHODOLOGY
64	SILICA	SOLID	SILICA	S : MINERALS P : MICRONIZED_SILICA_MANUFACTURING	S : INORGANICS_CHEMICAL P : SODIUM SILICATE MANUFACTURING	Recover silica	The aim of this synergy is to recover silica from micronized silica manufacturing and provide inorganic chemical industries for sodium silicate, pyrogenic silica, precipitated silica and silica gel manufacturing.	MATERIAL EXCHANGE	DIRECT	BEST PRACTICES
22	REFRACTORY PRODUCTS	SOLID	REFRACTORY PRODUCTS	S : STEEL P : ELECTRIC ARC FURNACE STEELMAKING AND CASTING MANUFACTURING	S : GLASS P : CONTAINER GLASS MANUFACTURING WITHOUT ABATEMENT SYSTEM	Are refractory products from steel industries compliant with refractory products used in Glass industries ?	The aim of this synergy is to recover refractory products from EAF to used them on glass industries for container glass manufacturing.	MATERIAL EXCHANGE	DIRECT	STRANE METHODOLOGY
24	SLAG	SOLID	SLAG	S : STEEL P : BLAST FURNACES MANUFACTURING	S : GLASS P : STONE AND SLAG WOOL MANUFACTURING	Recover and transport slag	The aim of this synergy is to recover blast furnace slag to provide glass sector for stone and slag wool manufacturing.	MATERIAL EXCHANGE	DIRECT	STRANE METHODOLOGY BREF BEST PRACTICES
23	SLAG	SOLID	SLAG	S : COMBUSTION PLANT P : COAL COMBUSTION	S : GLASS P : STONE AND SLAG WOOL MANUFACTURING	Recover and transport slag	The aim of this synergy is to recover combustion plant slag to provide glass sector for stone and slag wool manufacturing.	MATERIAL EXCHANGE	DIRECT	STRANE METHODOLOGY
68	FLY ASH	SOLID	SILICIUM ALUMINIUM CALCIUM	S : COMBUSTION_PLANT P : INTEGRATED_GASIFICATION_COMBINED_CYCLE	S : GLASS P : CONTAINER_GLASS_MANUFACTURING_WITH_ABATEMENT_SYSTEM	Extract mineral products (silicium, calcium, aluminium) from fly ash	The aim of this synergy is to recover fly ash and extract mineral products (silicium, calcium, aluminium) and provide glass manufacturing.	MATERIAL EXCHANGE	DIRECT	STRANE METHODOLOGY BEST PRACTICES
40	SLAG	SOLID	NON-FERROUS METALS	S : STEEL P : BLAST FURNACES MANUFACTURING	S : NON FERROUS METALS INDUSTRIES P : SECONDARY COPPER SMELTING PYROMETALLURGICAL ROUTE	Recover slag for non-ferrous metals supply	The aim of this synergy is to recover blast furnace slag to provide secondary copper smelting pyromatallurgical route.	MATERIAL EXCHANGE	DIRECT	STRANE METHODOLOGY
44	SAND	SOLID	SAND	S : FOOD DRINK AND MILK INDUSTRIES P : STRACH	S : NON FERROUS METALS INDUSTRIES P : PRIMARY ZINC PRODUTION	Recover sand	The aim of this synergy is to recover sand from food and drink industries and aluminium production.	MATERIAL EXCHANGE	DIRECT	STRANE METHODOLOGY
47	COKE OVEN GAS	GAS	COKE OVEN GAS	S : STEEL P : COKE OVEN PLANTS	S : COMBUSTION PLANT P : IRON AND STEEL PROCESS GASES COMBUSTION	Recover and make COG compliant for combustion plants	The aim of this synergy is to recover coke oven gas from coke ovens and provide combustion plants for iron and steel process gases combustion.	COMBUSTIBLE	DIRECT	STRANE METHODOLOGY BREF BEST PRACTICES
48	BLAST FURNACE GAS	GAS	BLAST FURNACE GAS	S : STEEL P : BLAST FURNACES MANUFACTURING	S : COMBUSTION PLANT P : IRON AND STEEL PROCESS GASES COMBUSTION	Recover and make BF gas compliant for combustion plants	The aim of this synergy is to recover blast furnace gas and provide combustion plants for iron and steel process gases combustion.	COMBUSTIBLE	DIRECT	STRANE METHODOLOGY BREF BEST PRACTICES
49	BASIC OXYGEN FURNACE GAS	GAS	BASIC OXYGEN FURNACE GAS	S : STEEL P : BASIC OXYGEN STEELMAKING AND CASTING MANUFACTURING	S : COMBUSTION PLANT P : IRON AND STEEL PROCESS GASES COMBUSTION	Recover and make BOF gas compliant for combustion plants	The aim of this synergy is to recover blast furnace gas and provide combustion plants for iron and steel process gases combustion.	COMBUSTIBLE	DIRECT	STRANE METHODOLOGY BREF BEST PRACTICES
67	COOLING WATER	LIQUID	COOLING WATER	S : REFINING MINERAL OIL AND GAS P : ALL PROCESSES	S : COMBUSTION_PLANT P : COAL_COMBUSTION	Reuse cooling water	The aim of this synergy is to reuse refining mineral oil and gas plants cooling water to supply a combustion plant cooling system. This case is a Kalendborg industrial symbiosis existing solution.	COOLING WATER	DIRECT	BEST PRACTICES
78	TAR	LIQUID	TAR	S : ORGANIC_CHEMICALS P : HYDROGEN_PEROXIDE_MANUFACTURING	S : COMBUSTION_PLANT P : WASTE_CO-INCINERATION	Recover tar for burning	The aim of this synergy is to recover tars from hydrogen peroxyde manufacturing and provide waste co-incineration.	COMBUSTIBLE	DIRECT	STRANE METHODOLOGY BREF
84	SLUDGE	SOLID	SLUDGE	S : ORGANIC_CHEMICALS P : VINYL_CHLORIDE_MONOMER_MANUFACTURING	S : COMBUSTION_PLANT P : WASTE_CO-INCINERATION	Recover sludge for inceration	The aim of this synergy is to recover sludges from vynile chloride monomer manufacturing and provide waste co-incineration.	COMBUSTIBLE	DIRECT	STRANE METHODOLOGY
82	WOOD WASTE	SOLID	WOOD WASTE BARK SAWDUST	S : PRODUCTION_OF_PULP_PAPER_AND_BOARD P : THE_SULPHITE_PULPING_PROCESS	S : COMBUSTION_PLANT P : INTEGRATED_GASIFICATION_COMBINED_CYCLE	Recover wood wastes	The aim of this synergy is to recover waste wood from pulp and paper production sector, and provide combustion plants.	COMBUSTIBLE	DIRECT	STRANE METHODOLOGY BREF
83	SOIL AND GREEN WASTES	SOLID	SLUDGE	S : FOOD_DRINK_AND_MILK_INDUSTRIES P : SUGAR_BEET	S : COMBUSTION_PLANT P : WASTE_CO-INCINERATION	Recover sludge for inceration	The aim of this synergy is to recover sludge from sugar beet production process to provide cement raw material preparation.	COMBUSTIBLE	DIRECT	STRANE METHODOLOGY BREF
60	DRINKING WATER TREATMENT SLUDGE	SOLID	NUTRIENTS NITROGEN PHOSPHORUS POTASSIUM MAGNESIUM CALCIUM	S : WASTE WATER TREATMENT INDUSTRIES P : DRINKING_WATER_TREATMENT_PROCESS	S : FERTILISERS P : CAN PRODUCTION	Recover nutrients (nitrogen, phosphorus, potassium, magnesium and calcium)	The aim of this synergy is to recover sludges from waste water treatment and provide fertilisers companies with recovered nutrients (nitrogen, phosphorus, potassium, magnesium and calcium)	MATERIAL EXCHANGE	DIRECT	BREF BEST PRACTICES
65	SULPHUR	SOLID	SULPHUR	S : REFINING MINERAL OIL AND GAS P : HYDRODESULPHURISATION_PROCESS	S : FERTILISERS P : ATS_FERTILISER	Recover sulphur	The aim of this synergy is to recover sulphur from refining industries and provide fertilisers production companies. This synergy is base on a real case.	MATERIAL EXCHANGE	DIRECT	BEST PRACTICES
90	COOLING WATER	LIQUID	COOLING WATER	S : PRODUCTION_OF_PULP_PAPER_AND_BOARD P : MECHANICAL_PULPING_AND_CHEMIMECHANICAL_PULPING	S : FERTILISERS P : CAN_PRODUCTION	Reuse cooling water	The aim of this synergy is to reuse production of pulp and paper plants cooling water to supply fertilisers industries cooling system.	COOLING WATER	DIRECT	STRANE METHODOLOGY
66	BLAST FURNACE AND CONVERTER SLAG	SOLID	BLAST FURNACE SLAG	S : STEEL P : BLAST_FURNACES_MANUFACTURING	S : CERAMIC P : BRICKS_AND_ROOF_TILES_MANUFACTURING	Recover BF slag as a mineral source	The aim of this synergy is to recover blast furnace slag to provide brick and roof tiles manufacturing in ceramics industries.	MATERIAL EXCHANGE	DIRECT	BEST PRACTICES STRANE METHODOLOGY
69	FLY ASH	SOLID	SILICIUM ALUMINIUM CALCIUM	S : COMBUSTION_PLANT P : COAL_COMBUSTION	S : CERAMIC P : BRICKS_AND_ROOF_TILES_MANUFACTURING	Extract mineral products (silicium, calcium, aluminium) from fly ash	The aim of this synergy is to recover fly ash and extract mineral products (silicium, calcium, aluminium) to provide brick and roof tiles manufacturing.	MATERIAL EXCHANGE	DIRECT	STRANE METHODOLOGY BEST PRACTICES
36	LIME	SOLID	LIME	S : PRODUCTION OF PULP PAPER AND BOARD P : THE KRAFT PULPING PROCESS	S : WASTE INCINERATION P : FLUE GAS TREATMENT NH	Recover Lime	The aim of this synergy is to recover lime from kraft pulping process in pulp and paper production sector, and providewaste incineration plant for flue gas treatment.	MATERIAL EXCHANGE	DIRECT	STRANE METHODOLOGY BREF
87	WOOD WASTE	SOLID	WOOD	S : PRODUCTION_OF_PULP_PAPER_AND_BOARD P : THE_SULPHITE_PULPING_PROCESS	S : LIME P : LIME_MANUFACTURING_LONG_ROTARY_KILN	Recover wood wastes	The aim of this synergy is to recover waste wood from pulp and paper production sector, and provide combustion plants.	COMBUSTIBLE	DIRECT	STRANE METHODOLOGY BREF BEST PRACTICES
89	COOLING WATER	LIQUID	COOLING WATER	S : PRODUCTION_OF_PULP_PAPER_AND_BOARD P : MECHANICAL_PULPING_AND_CHEMIMECHANICAL_PULPING	S : REFINING_MINERAL_OIL_AND_GAS P : ALL_PROCESSES	Reuse cooling water	The aim of this synergy is to reuse production of pulp and paper plants cooling water to supply refining industries cooling system.	COOLING WATER	DIRECT	STRANE METHODOLOGY
97	OIL	LIQUID	OIL	S : WASTE TREATMENTS INDUSTRIES P : WASTE TREATMENT AIMED PRODUCE MATERIAL USED AS FUEL	S : See table n° P : See table n°	Make oil compliant with receiver processes	The purpose of this synergy is to provide industries with fuels from industrial wastes rather than using traditional fuels.	WASTE FOR FUEL PREPARATION	DIRECT	STRANE METHODOLOGY
98	BITUMEN	LIQUID	BITUMEN	S : WASTE TREATMENTS INDUSTRIES P : WASTE TREATMENT AIMED PRODUCE MATERIAL USED AS FUEL	S : See table n° P : See table n°	Make bitumen compliant with receiver processes	The purpose of this synergy is to provide industries with fuels from industrial wastes rather than using traditional fuels.	WASTE FOR FUEL PREPARATION	DIRECT	STRANE METHODOLOGY
99	METHANOL	LIQUID	METHANOL	S : WASTE TREATMENTS INDUSTRIES P : WASTE TREATMENT AIMED PRODUCE MATERIAL USED AS FUEL	S : See table n° P : See table n°	Make methanol compliant with receiver processes	The purpose of this synergy is to provide industries with fuels from industrial wastes rather than using traditional fuels.	WASTE FOR FUEL PREPARATION	DIRECT	STRANE METHODOLOGY
100	GAS OIL	LIQUID	GAS OIL	S : WASTE TREATMENTS INDUSTRIES P : WASTE TREATMENT AIMED PRODUCE MATERIAL USED AS FUEL	S : See table n° P : See table n°	Make gas oil compliant with receiver processes	The purpose of this synergy is to provide industries with fuels from industrial wastes rather than using traditional fuels.	WASTE FOR FUEL PREPARATION	DIRECT	STRANE METHODOLOGY

DATA SET 2: PROCEDURE AND TECHNOLOGY CHARACTERIZATION + TRANSPORT

DATA SET 3: PROCEDURE/TECHNOLOGY INPUT, OUTPUT AND COST ANALYSIS

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).

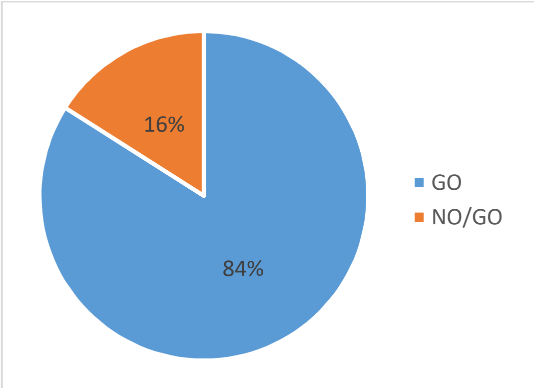

Figure 7 – Final technical viability evaluation (GO and NO/GO)

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).

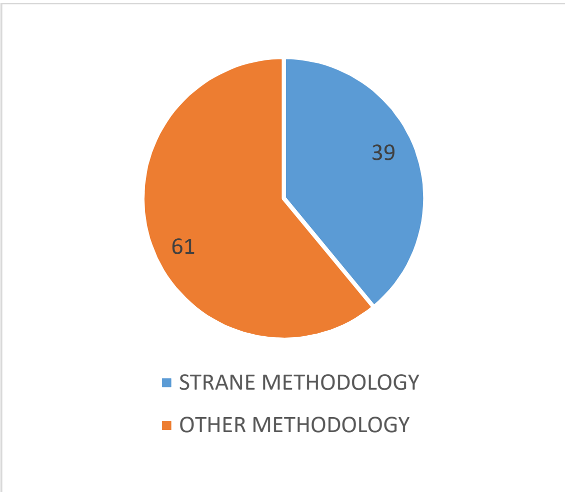

Figure 8 – Synergies divided by identification source

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.

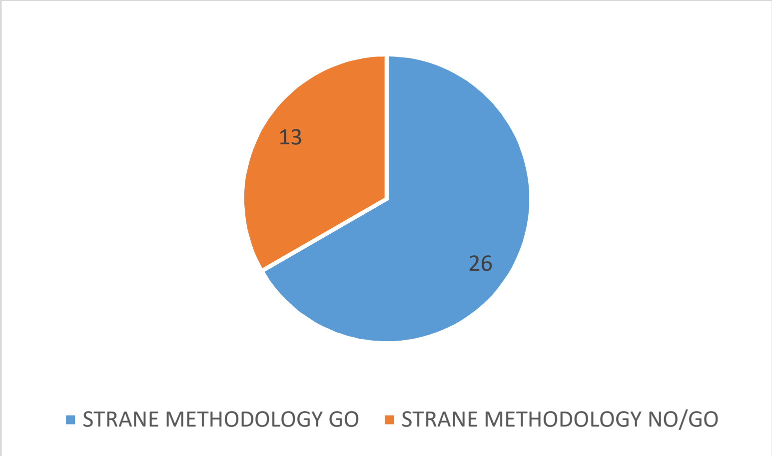

Figure 9 – Strane methodology synergies technical evaluation (GO/NOGO)

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.

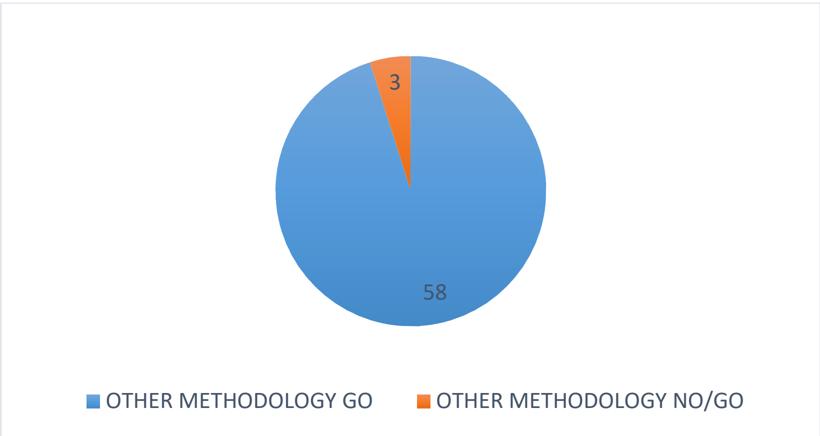

Figure 10 – Other methodologies synergies technical evaluation (GO/NOGO)

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 %

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

Synergy number	Initial Status	Possible Status	Comments
6	Direct	Indirect	Optionally turned into indirect in order to improve its quality as a raw material for cement production.
65	Direct	Indirect	Associated to compulsory desulphurization process requirements.
22	Direct	Indirect	Compulsory indirect due to high demand of processing involved. Technology is not at optimum state of development.
5	Indirect	Direct	Waelz kiln technology is already implemented for secondary Zinc production. EAF Dust can be directly sent to this receiver.
9/10/39	Indirect	Direct	Sulphuric acid recovery is already a standard in this sender sector. Equipment to produce Sulphuric Acid is already available at this sender process.
31/32	Indirect	Direct	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.
85	Indirect	Direct	Processing of wastewaters containing oil is already a standard technology in this sender process. Recovered oil can be directly sent to final users.
41	Indirect	Direct	Processing of ash is current practice in this sender sector.
59	Indirect	Direct	Processing of slag ash is current practice in this sender sector.
18	Indirect	Direct	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.
19	Indirect	Direct	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.
94	Indirect	Direct	Steam can be used directly without any treatment or technology requirements.

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

- ➢ 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
  -etc….

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

Synergy 1

Bermúdez, J. M., Arenillas, A., Luque, R., & Menéndez, J. A. (2013). An overview of novel technologies to valorise coke oven gas surplus. *Fuel Processing Technology*, *110*, 150–159. https://doi.org/10.1016/j.fuproc.2012.12.007

JRC 2016 BREF Common Waste Water and Waste Gas Treatment/ Management Systems in the Chemical Sector

Ramírez-santos, Á. A., Castel, C., & Favre, E. (2017). A review of gas separation technologies within emission reduction programs in the iron and steel sector: Current application and development perspectives. *Separation and Purification Technology*. https://doi.org/10.1016/j.seppur.2017.11.063

Synergy 2

Bermúdez, J. M., Ferrera-Lorenzo, N., Luque, S., Arenillas, A., & Menéndez, J. A. (2013). New process for producing methanol from coke oven gas by means of CO 2 reforming. Comparison with conventional process. *Fuel Processing Technology*, *115*, 215–221. https://doi.org/10.1016/j.fuproc.2013.06.006

JRC 2012 BREF Iron and Steel Production

Synergy 3

Barker, G. (2018). *The Engineer's Guide to Plant Layout and Piping Design for the Oil and Gas Industries*. https://doi.org/10.1016/B978-0-12-814653-8.00011-4

Synergy 4

API. Retrieved from https://www.api.org/~/media/Files/Oil-and-Natural-Gas/Refining/API-guidance-doc-storage-handling-petroleum-coke.pdf

JRC 2017 BREF Production of Large Volume Organic Chemicals

Synergy 5

JRC 2016 BREF Non-ferrous Metals Industries

Rütten, J., Frias, C., Diaz, G., Martin, D., Sanchez, F., & Reunidas, T. (n.d.). Processing EAF Dust Through Waelz Kiln and ZINCEX TM Solvent Extraction : The Optimum Solution, 1673–1688.

Synergy 6

Chandini, R. (2020). Use of Steel Slag in Concrete as Fine Aggregate, *7*(4), 34–41.

Guo, H., Yin, S., Yu, Q., Yang, X., Huang, H., Yang, Y., & Gao, F. (2018). Resources, Conservation & Recycling Iron recovery and active residue production from basic oxygen furnace (BOF) slag for supplementary cementitious materials. *Resources, Conservation & Recycling*, *129*(July 2017), 209–218. https://doi.org/10.1016/j.resconrec.2017.10.027

Yilmaz, M., & Karago, S. (2009). Concrete Produced by Steel - Making Slag (Basic Oxygen Furnace) Concrete Produced by Steel-Making Slag (Basic Oxygen Furnace) Addition in Portland Cement, (November). https://doi.org/10.1111/j.1744-7402.2008.02317.x

Synergy 7

Gazquez, M. J., Bolivar, J. P., Vaca, F., García-tenorio, R., & Caparros, A. (2013). Cement & Concrete Composites Evaluation of the use of TiO 2 industry red gypsum waste in cement production. *Cement and Concrete Composites*, *37*, 76–81. https://doi.org/10.1016/j.cemconcomp.2012.12.003

Synergy 8

Caillahua, M. C., & Moura, F. J. (2017). Technical feasibility for use of FGD gypsum as an additive setting time retarder for Portland cement. *Integrative Medicine Research*, (x x), 1–8. https://doi.org/10.1016/j.jmrt.2017.08.005

Duan, P. X., Zhang, Y., Miao, Y. C., & Li, Y. (2012). A Study of the Influence of FGD Gypsum Used as Cement Retarder on the Properties of Concrete, *377*, 1311–1319. https://doi.org/10.4028/www.scientific.net/AMR.374-377.1311

Increasing the use of synthetic gypsum in the cement industry. (2016). Carmi, Gennady, Schutt, Michael.

Tzouvalas, G., Tsimas, S., & Papageorgiou, A. J. FGD GYPSUM – A promising industrial by-product for the Greek cement industry.

Wang, X., & Deng, J. (2015). Advances in Utilization of Flue Gas Desulfurization Gypsum, (Icadme), 1207–1213.

Synergy 9

Almirall, B. X. (2009). Introduction to Wet Sulfuric Acid Plants Optimization Through Exergoeconomics Kurzfassung, (June).

Iron and Steel Production in France. (2015). *Scientific American*, *44*(1143supp), 18268–18268. https://doi.org/10.1038/scientificamerican11271897-18268csupp

Rosenberg, H. (2006). Topsoe wet gas sulphuric acid (WSA) technology—an attractive alternative for reduction of sulphur emissions from furnaces and converters. *… Platinum Conference "Platinum Surges Ahead", The …*, 191–198. Retrieved from http://www.basemetals.org/Pt2006/Papers/191-198_Rosenberg.pdf

Synergy 10

Almirall, B. X. (2009). Introduction to Wet Sulfuric Acid Plants Optimization Through Exergoeconomics Kurzfassung, (June).

Iron and Steel Production in France. (2015). *Scientific American*, *44*(1143supp), 18268–18268. https://doi.org/10.1038/scientificamerican11271897-18268csupp

Rosenberg, H. (2006). Topsoe wet gas sulphuric acid (WSA) technology—an attractive alternative for reduction of sulphur emissions from furnaces and converters. *… Platinum Conference "Platinum Surges Ahead", The …*, 191–198. Retrieved from http://www.basemetals.org/Pt2006/Papers/191-198_Rosenberg.pdf

Synergy 11

Prevention, I. P. (2007). Large Volume Inorganic Chemicals - Solids and Others industry, *I*(August).

Synergy 12

LabChem Inc. Sodium Chloride Solutions, 0.5% - 30% w/v. Retrieved from https://www.southlandmed.com/pdf/labchem_lc23460_msds.pdf?fbclid=IwAR2avy_1OeED68yV7JvzJIQhPhW0J_iwMxpMUKP7S14SuOX7tZHX2rzG0eA

JRC 2016 BREF Non-ferrous Metals Industries

Synergy 13

Boopathy, R., Karthikeyan, S., Mandal, A. B., & Sekaran, G. Clean Technologies and Environmental Policy. Retrieved from https://www.academia.edu/1856307/Characterisation_and_recovery_of_sodium_chloride_from_salt-laden_solid_waste_generated_from_leather_industry

JRC 2005 BREF Slaughterhouses and Animals By-products Industries

Synergy 14

JRC 2017 BREF Production of Large Volume Organic Chemicals

Prevention, I. P. (2006). Waste Incineration, (August).

Synergy 15

Hotza, D., Labrincha, J. A., Montedo, O. R. K., Federal, U., Catarina, D. S., Federal, U., Catarina, D. S., & Aveiro, U. De. (2018). Wastes from pulp and paper mills - a review of generation and recycling alternatives (Resíduos da produção de papel e celulose - uma revisão, *64*, 443–453.

Manocha, S., & Ponchon, F. (2018). Management of Lime in Steel, 1–16. https://doi.org/10.3390/met8090686

Synergy 16

Almirall, B. X. (2009). Introduction to Wet Sulfuric Acid Plants Optimization Through Exergoeconomics Kurzfassung, (June).

Iron and Steel Production in France. (2015). *Scientific American*, *44*(1143supp), 18268–18268. https://doi.org/10.1038/scientificamerican11271897-18268csupp

Rosenberg, H. (2006). Topsoe wet gas sulphuric acid (WSA) technology—an attractive alternative for reduction of sulphur emissions from furnaces and converters. … *Platinum Conference "Platinum Surges Ahead", The* …, 191–198. Retrieved from http://www.basemetals.org/Pt2006/Papers/191-198_Rosenberg.pdf

Synergy 17

JRC 2017 BREF Production of Large Volume Organic Chemicals

JRC 2014 BREF Refining of Mineral Oil and Gas

Synergy 18

JRC 2017 BREF Production of Large Volume Organic Chemicals

JRC 2014 BREF Refining of Mineral Oil and Gas

Synergy 19

JRC 2017 BREF Production of Large Volume Organic Chemicals

JRC 2014 BREF Refining of Mineral Oil and Gas

Synergy 20

Cheng, C. Y., & Urbani, M. D. (2015). The recovery of nickel and cobalt from leach solutions by solvent extraction: process overview, recent research and development, (January 2005), 503–526.

Hawker, W., Vaughan, J., Jak, E., & Hayes, P. C. (2018). The Synergistic Copper Process concept. *Mineral Processing and Extractive Metallurgy: Transactions of the Institute of Mining and Metallurgy*, *127*(4), 210–220. https://doi.org/10.1080/03719553.2017.1375768

Synergy 21

Engineering Air liquid. Retrieved from https://www.engineering-airliquide.com/oxyclaustm-sulfur-recovery-unit

JRC 2014 BREF Refining of Mineral Oil and Gas

Synergy 22

Fang, H., Smith, J. D., & Peaslee, K. D. (1999). Study of spent refractory waste recycling from metal manufacturers in Missouri, *25*, 111–124.

Hanagiri, S. (2008). Recent Improvement of Recycling Technology for Refractories, (98), 93–98.

Horckmans, L., Nielsen, P., Dierckx, P., & Ducastel, A. (2019). Resources, Conservation & Recycling of refractory bricks used in basic steelmaking: A review. *Resources, Conservation & Recycling*, *140*(May 2018), 297–304. https://doi.org/10.1016/j.resconrec.2018.09.025

REFRASORT project. Retrieved from https://cordis.europa.eu/project/rcn/110889/reporting/en

Synergy 23

JRC 2012 BREF Manufacture of Glass

Synergy 24

Global CC Institute. Retrieved from https://hub.globalccsinstitute.com/publications/51-introduction-blast-furnace-slag-and-steel-furnace-slag-applications

Synergy 25

Shoira, M. (2006). Application of defecation lime from sugar industry in Uzbekistan.

Synergy 26

Maheswaran, S., Kumar, V. R., & Bhuvaneshwari, B. (2011). Studies on lime sludge for partial replacement of cement, *78*, 1015–1019. https://doi.org/10.4028/www.scientific.net/AMM.71-78.1015

Synergy 27

JRC 2016 BREF Non-ferrous Metals Industries

Synergy 28

Associate, S. S. J., & Budhgaon, P. (2017). Beneficial Reuse of Waste Foundry Sand in Concrete, *7*(3), 74–95.

Synergy 29

Liu, X., & Zhang, N. (2011). Utilization of red mud in cement production: a review. https://doi.org/10.1177/0734242X11407653

Practice, B. (2015). Bauxite Residue Management, (July).

Synergy 30

Ding, Y., Cheng, T., Liu, P., & Lee, W. (2017). Study on the treatment of BOF slag to replace fine aggregate in concrete. *Construction and Building Materials*, *146*, 644–651. https://doi.org/10.1016/j.conbuildmat.2017.04.164

911 Metallurgist. Retrieved from https://www.911metallurgist.com/cement-blast-furnace-slag-manufacturing

Smith, M. A. (1975). The economic and environmental benefits of increased use of pfa and granulated slag, (March), 154–170.

Synergy 31

Altek. Retrieved from https://www.altek-al.com/index.html

JRC 2016 BREF Non-ferrous Metals Industries

JRC 2013 BREF Production of Cement, Lime and Magnesium Oxide

Reuter, M., Xiao, Y., and Boin, U. (2004). Recycling and Environmental Issues of Metallurgical Slags and Salt Fluxes. *VII International Conference on MoltenSlags Fluxes and Salts*, 349–356.

Synergy 32

Altek. Retrieved from https://www.altek-al.com/index.html

JRC 2016 BREF Non-ferrous Metals Industries

JRC 2012 BREF Manufacture of Glass

Reuter, M., Xiao, Y., and Boin, U. (2004). Recycling and Environmental Issues of Metallurgical Slags and Salt Fluxes. *VII International Conference on MoltenSlags Fluxes and Salts*, 349–356.

Synergy 33

Bunge, R. (2015). *RECOVERY OF METALS FROM WASTE INCINERATOR BOTTOM ASH*.

Synergy 34

Nomura, T., Yamamoto, N., Fujii, T., & Takiguchi, Y. (2015). Beneficiation Plants and Pelletizing Plants for Utilizing Low Grade Iron Ore, (33), 8–15.

Report 2015 BOTTOM ASH FROM WTE PLANTS METAL RECOVERY AND. (2015), 1–30.

Synergy 35

Tossavainen, M., Engstrom, F., Yang, Q., & Menad, N. (2007). Characteristics of steel slag under different cooling conditions, *27*, 1335–1344. https://doi.org/10.1016/j.wasman.2006.08.002

Tsakiridis, P. E., Papadimitriou, G. D., Tsivilis, S., & Koroneos, C. (2008). Utilization of steel slag for Portland cement clinker production Utilization of steel slag for Portland cement clinker production, (May). https://doi.org/10.1016/j.jhazmat.2007.07.093

Synergy 36

Dastgheib, S. A., Salih, H., Li, J., & Patterson, C. (2018). Reuse of Water Utility Lime Sludge for Flue Gas Desulfurization in Coal-Fired Power Plants: Part II. Lime Sludge Characterization and Mercury Reemission. https://doi.org/10.1021/acs.energyfuels.8b00824

Hotza, D., Labrincha, J. A., Montedo, O. R. K., Federal, U., Catarina, D. S., Federal, U., Catarina, D. S., & Aveiro, U. De. (2018). Wastes from pulp and paper mills - a review of generation and recycling alternatives (Resíduos da produção de papel e celulose - uma revisão), *64*, 443–453.

Löschau, M., & Karpf, R. (n.d.). Flue Gas Treatment – State of the Art.

Synergy 37

JRC 2016 BREF Non-ferrous Metals Industries

Rütten, J., Frias, C., Diaz, G., Martin, D., Sanchez, F., & Reunidas, T. (n.d.). Processing EAF Dust Through Waelz Kiln and ZINCEX TM Solvent Extraction: The Optimum Solution, 1673–1688.

Synergy 38

Agency, U. S. E. P. (1984). *Benzene Emissions from Coke By-product Recovery Plants, Background Information for Revised Proposed Standards: Environmental Impact Statement*.

EMIS. Retrieved from https://emis.vito.be/en/techniekfiche/gas-scrubbing-general

JRC 2012 BREF Iron and Steel Production

Synergy 39

Almirall, B. X. (2009). Introduction to Wet Sulfuric Acid Plants Optimization Through Exergoeconomics Kurzfassung, (June).

Iron and Steel Production in France. (2015). *Scientific American*, *44*(1143supp), 18268–18268. https://doi.org/10.1038/scientificamerican11271897-18268csupp

Rosenberg, H. (2006). Topsoe wet gas sulphuric acid (WSA) technology—an attractive alternative for reduction of sulphur emissions from furnaces and converters. … *Platinum Conference "Platinum Surges Ahead", The …*, 191–198. Retrieved from http://www.basemetals.org/Pt2006/Papers/191-198_Rosenberg.pdf

Synergy 40

JRC 2016 BREF Non-ferrous Metals Industries

Synergy 41

Bunge, R. (2015). *RECOVERY OF METALS FROM WASTE INCINERATOR BOTTOM ASH.*

Synergy 42

Hu, G., Li, J., & Zeng, G. (2013). *Recent development in the treatment of oily sludge from petroleum industry: A review. Journal of Hazardous Materials* (Vol. 261). Elsevier B.V. https://doi.org/10.1016/j.jhazmat.2013.07.069

Synergy 43

Hawker, W., Vaughan, J., Jak, E., & Hayes, P. C. (2018). The Synergistic Copper Process concept. *Mineral Processing and Extractive Metallurgy: Transactions of the Institute of Mining and Metallurgy*, *127*(4), 210–220. https://doi.org/10.1080/03719553.2017.1375768

911 Metallurgy. Retrieved from https://www.911metallurgist.com/electrowinning/

Synergy 44

Perindustrian, M., & Ariffin, K. S. (2004). What is Silica ?, 1–7.

Synergy 45

Zhou, J., Hao, S., Huang, W., Mu, X., Yang, J., & Liu, W. (2014). Recycling sodium dichromate in sodium chlorate crystallization mother liquor by nanofiltration membrane, *9*(12), 581–585. https://doi.org/10.5897/SRE2014.5981

Synergy 46

Mordoğan, H., Çïçek, T., & Işik, A. (1999). Caustic soda leach of electric arc furnace dust. *Turkish Journal of Engineering and Environmental Sciences*, *23*(3), 199–207.

Synergy 47

JRC 2012 BREF Iron and Steel Production

Synergy 48

JRC 2012 BREF Iron and Steel Production

Synergy 49

JRC 2012 BREF Iron and Steel Production

JRC 2006 BREF Waste Incineration

Synergy 50

The use of limestone powder as an alternative cement replacement material: an experimental study. Wendimu Gudissa and Abebe Dinku Department of Civil Engineering. (2010), *27*.

Prevention, I. P. (2007). Large Volume Inorganic Chemicals - Solids and Others industry, *I*(August).

Synergy 51

JRC 2006 BREF Waste Incineration

Quina, M. J., Bordado, J. C., & Quinta-Ferreira, R. M. (2008). Treatment and use of air pollution control residues from MSW incineration: An overview. *Waste Management*, *28*(11), 2097–2121. https://doi.org/10.1016/j.wasman.2007.08.030

Synergy 52

Bonner, F. J., & Donatelli, A. A. (2001). University of Massachusetts Lowell Diffusion Dialysis and Acid Recovery in Metal Operations Toxics use Reduction Institute University Research in Sustainable.

Cullivan, J., & Cullivan, B. Economic and Chemical Comparisons of Hydrochloric Acid Recovery Technologies for Iron Pickling Operations, 1–12.

Eco-Tec. Retrieved from https://www.eco-tec.com/products/hydrometallurgy/nickel-cobalt-recovery-system-for-copper-refinery/

Khan, M. I., Wu, L., Hossain, M., Pan, J., Ran, J., Mondal, A. N., & Xu, T. (2015). Preparation of diffusion dialysis membrane for acid recovery via a phase-inversion method, *5*, 365–378.

Milestones. Retrieved from https://milestonesci.com/acid-purification-systems/

Recycling, A., Plating, E., Saving, C., Dialysis, D., & Law, T. HCl Acid Recycling Case Study.

Savillex. Retrieved from https://www.savillex.com/

Savillex. DST-1000 Acid Purification System DST-1000 Acid Purification System.

Savillex. DST-4000 Acid Purification System DST-4000 Acid Purification System.

Synergy 53

Ayres, D. M., Davis, A. P., & Gietka, P. M. (1994). Removing Heavy Metals from Wastewater, (August).

Barthe, P., Chaugny, M., & Roudier, S. (2015). *Best Available Techniques (BAT) Reference Document for the Refining of Mineral Oil and Gas Prevention and Control)*. https://doi.org/10.2791/010758

Cole, P. M., Sole, K. C., & Cole, P. M. (2017). Mineral Processing and Extractive Metallurgy Review Zinc solvent extraction in the process industries, *7508*(November). https://doi.org/10.1080/08827500306897

Cusano, G., Rodrigo Gonzalo, M., Farrell, F., Remus, R., Roudier, S., & Delgado Sancho, L. (2017). *Best Available Techniques (BAT) Reference Document for the Non-Ferrous Metals Industries - Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control)*. https://doi.org/doi:10.2760/8224

Engineering, R. (2000). ALUMINUM RECOVERY, 13–16.

Tsakiridis, P. E., Oustadakis, P., & Katsiapi, A. (2010). Hydrometallurgical process for zinc recovery from electric arc furnace dust (EAFD). Part II: Downstream processing and zinc recovery by electrowinning. *Journal of Hazardous Materials*, *179*(1–3), 8–14. https://doi.org/10.1016/j.jhazmat.2010.04.004

Synergy 54

Brinkmann, Thomas; Santonja, Germán Giner; Yükseler, Hande; Roudier, Serge; Sancho, L. D. (2016). *Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control)*.

Environmental Protection Agency. (2000). Wastewater Technology Fact Sheet. *United States Environmental Protection Agency*, 1–7. https://doi.org/EPA 832-F-99-062

Kinidi, L., Ai, I., Tan, W., Binti, N., Wahab, A., Fikri, K., Tamrin, B., Hipolito, C. N., & Salleh, S. F. (2018). Recent Development in Ammonia Stripping Process for Industrial Wastewater Treatment, *2018*.

Synergy 55

Brinkmann, Thomas; Santonja, Germán Giner; Yükseler, Hande; Roudier, Serge; Sancho, L. D. (2016). *Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control)*.

Environmental Protection Agency. (2000). Wastewater Technology Fact Sheet. *United States Environmental Protection Agency*, 1–7. https://doi.org/EPA 832-F-99-062

Kinidi, L., Ai, I., Tan, W., Binti, N., Wahab, A., Fikri, K., Tamrin, B., Hipolito, C. N., & Salleh, S. F. (2018). Recent Development in Ammonia Stripping Process for Industrial Wastewater Treatment, *2018*.

Synergy 56

Barthe, P., Chaugny, M., & Roudier, S. (2015). *Best Available Techniques (BAT) Reference Document for the Refining of Mineral Oil and Gas Prevention and Control)*. https://doi.org/10.2791/010758

Cole, P. M., Sole, K. C., & Cole, P. M. (2017). Mineral Processing and Extractive Metallurgy Review Zinc solvent extraction in the process industries, *7508*(November). https://doi.org/10.1080/08827500306897

Cusano, G., Rodrigo Gonzalo, M., Farrell, F., Remus, R., Roudier, S., & Delgado Sancho, L. (2017). *Best Available Techniques (BAT) Reference Document for the Non-Ferrous Metals Industries - Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control).* https://doi.org/doi:10.2760/8224

Barthe, P., Chaugny, M., & Roudier, S. (2015). *Best Available Techniques (BAT) Reference Document for the Refining of Mineral Oil and Gas Prevention and Control).* https://doi.org/10.2791/010758

Tsakiridis, P. E., Oustadakis, P., & Katsiapi, A. (2010). Hydrometallurgical process for zinc recovery from electric arc furnace dust (EAFD). Part II: Downstream processing and zinc recovery by electrowinning. *Journal of Hazardous Materials*, *179*(1–3), 8–14. https://doi.org/10.1016/j.jhazmat.2010.04.004

Synergy 57

Engineering, R. (2000). ALUMINUM RECOVERY, 13–16.

JRC 2016 BREF Non-ferrous Metals Industries

Petruzzelli, D., Limoni, N., Tiravanti, G., & Passino, R. (1998). Aluminum recovery from water clarifier sludges by ion exchange Comparison of strong and weak electrolyte cation resins performances, *38*, 227–236.

Synergy 58

Bonner, F. J., & Donatelli, A. A. (2001). University of Massachusetts Lowell Diffusion Dialysis and Acid Recovery in Metal Operations Toxics use Reduction Institute University Research in Sustainable.

Cullivan, J., & Cullivan, B. (n.d.). Economic and Chemical Comparisons of Hydrochloric Acid Recovery Technologies for Iron Pickling Operations, 1–12.

Eco-Tec. Retrieved from https://www.eco-tec.com/products/hydrometallurgy/nickel-cobalt-recovery-system-for-copper-refinery/

Khan, M. I., Wu, L., Hossain, M., Pan, J., Ran, J., Mondal, A. N., & Xu, T. (2015). Preparation of diffusion dialysis membrane for acid recovery via a phase-inversion method, *5*, 365–378.

Milestones. Retrieved from https://milestonesci.com/acid-purification-systems/

Recycling, A., Plating, E., Saving, C., Dialysis, D., & Law, T. HCl Acid Recycling Case Study.

Savillex. Retrieved from https://www.savillex.com/

Savillex. DST-1000 Acid Purification System DST-1000 Acid Purification System.

Savillex. DST-4000 Acid Purification System DST-4000 Acid Purification System.

Synergy 59

Bunge, R. (2015). *RECOVERY OF METALS FROM WASTE INCINERATOR BOTTOM ASH.*

Synergy 60

Costa, I., & Ferrão, P. (2010). A case study of industrial symbiosis development using a middle-out approach, *18*, 984–992. https://doi.org/10.1016/j.jclepro.2010.03.007

Kominko, H., Gorazda, K., & Wzorek, Z. (2017). The Possibility of Organo-Mineral Fertilizer Production from Sewage Sludge The Possibility of Organo-Mineral Fertilizer Production from Sewage Sludge. *Waste and Biomass Valorization*, *0*(0), 0. https://doi.org/10.1007/s12649-016-9805-9

Kominko, H., Gorazda, K., Wzorek, Z., & Wojtas, K. (2017). Sustainable Management of Sewage Sludge for the Production of Organo-Mineral Fertilizers. *Waste and Biomass Valorization*, *0*(0), 0. https://doi.org/10.1007/s12649-017-9942-9

Synergy 61

Herbold Meckesheim. Retrieved from https://www.herbold.com/

Vito and Bio. Fact sheet E6 - Mechanical Recyling of Plastics.

WOŹNIAK, K. (2013). Plastic blasting and deflashing media in shot blasting treatment, (12).

Synergy 62

Baeshen, N. A., Baeshen, M. N., Sheikh, A., Bora, R. S., Ahmed, M. M. M., Ramadan, H. A. I., Saini, K. S., & Redwan, E. M. (2014). Cell factories for insulin production, 1–9.

SUSTAINABLE INDUSTRIAL DESIGN AND WASTE MANAGEMENT. Retrieved from https://www.elsevier.com/books/sustainable-industrial-design-and-waste-management/el-haggar/978-0-12-373623-9

Beckman. Retrieved from https://www.beckman.pt/centrifuges/high-speed/avanti-j-hc

Synergy 63

Adriano, R., & Maura, M. (2003). European Patent EP1314710 - A Process of maturing and stabilizing biomasses under reduction of smelling emissions.

Synergy 64 - NO REF

Synergy 65

Lunt, R. R., & Cunic, J. D. (2000). *Profiles in Flue Gas Desulfurization*. American Institute of Chemical Engineers. https://doi.org/10.1002/9780470935446

Synergy 66

Cunico, L., Dircetti, G., Dondi, M., Ercolani, G., Guarini, G., Mazzanti, F., Raimondo, M., Ruffini, A., & Venturi, I. (2003). Steel Slag Recycling in Clay Brick Production, (January).

Synergy 67 - NO REF

Synergy 68

Sheng, J., Huang, B. X., Zhang, J., Zhang, H., Sheng, J., Yu, S., & Zhang, M. (2003). Production of glass from coal fly ash q, *82*, 181–185.

Technical, I. (n.d.). Journal of Environmental Science and Health, Part A: Toxic / Hazardous Substances and Environmental Engineering. The Recycling of the Coal Fly Ash in Glass Production, (December 2014), 37–41. https://doi.org/10.1080/10934520600779208

Synergy 69

Luo, Y., Zheng, S., Ma, S., Liu, C., & Wang, X. (2018). Ceramic tiles derived from coal fly ash: Preparation and mechanical characterization Ceramic tiles derived from coal fly ash: Preparation and mechanical characterization. *Ceramics International*, *43*(15), 11953–11966. https://doi.org/10.1016/j.ceramint.2017.06.045

Oueralt, I., Ouerol, X., Lopez-Soler, A., & Plana, F. (1997). Use of coal fly ash for ceramics: a case study for a large Spanish power station, *76*(8), 787–791.

Synergy 70

Chironna, R. J. (2011). Wet scrubbing of acidic gases, (June).

CIBO Estimated Capital Costs For Air Pollution Control Equipment For Coal-Fired Industrial Boilers.

Directive, I. E. (2016). *Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control)*.

JRC 2018 BREF Waste Treatment

Monroe Environmental. Retrieved from https://www.monroeenvironmental.com/portfolio-items/wet-scrubber-treats-hcl-cl2-from-rto/

Taylor, P., & Baasel, W. D. (2012). Capital and Operating Costs of Wet Scrubbers, (October 2014), 37–41. https://doi.org/10.1080/08940630.1988.10466384

Synergy 71

Hait, J., Jana, R. K., & Sanyal, S. K. (2012). Processing of copper electrorefining anode slime: a review. *Mineral Processing and Extractive Metallurgy*, *118*(4), 240–252. https://doi.org/10.1179/174328509x431463

JRC 2016 BREF Non-ferrous Metals Industries

JRC 2014 BREF Refining of Mineral Oil and Gas

Seisko, S., Aromaa, J., Latostenmaa, P., Forsen, O., Wilson, B., & Lundstrom, M. (2017). Pressure leaching of decopperized copper electrorefining anode slimes in strong acid solution. *Physicochemical Problems of Mineral Processing*, *53*(1), 465–474. https://doi.org/10.5277/ppmp170136

The, O., Quality, R., & Palladium, O. F. (2011). CONTENTS CONTENTS, (September), 193–196.

Synergy 72

Manskinen, K., Nurmesniemi, H., & Pöykiö, R. (2011). Total and extractable non-process elements in green liquor dregs from the chemical recovery circuit of a semi-chemical pulp mill. *Chemical Engineering Journal*, *166*(3), 954–961. https://doi.org/10.1016/j.cej.2010.11.082

Mäkelä, M., Geladi, P., Grimm, A., Dahl, O., Pietiläinen, A., & Larsson, S. H. (2016). Cyclone processing of green liquor dregs (GLD) with results measured and interpreted by ICP-OES and NIR spectroscopy, *304*, 448–453. https://doi.org/10.1016/j.cej.2016.06.107

Steen, C. (2016). Separation and Utilization of Solid Residue Streams from Kraft Pulp Mills.

Universitatis, A. (n.d.). Novel treatment methods for green liquor dregs and enhancing circular novel treatment methods for green liquor dregs and enhancing circular.

Vakkilainnen, E. K. (n.d.). The Kraft chemical recovery process, 1–8.

Synergy 73

Barakat, M. A., Mahmoud, M. H. H., & Mahrous, Y. S. (2006). Recovery and separation of palladium from spent catalyst, *301*, 182–186. https://doi.org/10.1016/j.apcata.2005.11.028

Gaugler, R. . (1963). United States Patent Office 2997744, 1–2.

JRC 2014 BREF Refining of Mineral Oil and Gas

Pietrelli, L., & Fontana, D. (2013). Automotive spent catalysts treatment and platinum recovery Loris Pietrelli * and Danilo Fontana, (February 2015). https://doi.org/10.1504/IJEWM.2013.051845

Nikoloski, A. N., & Ang, K. Mineral Processing and Extractive Metallurgy Review: An International Review of the Application of Ion Exchange Resins for the Recovery of Platinum-Group Metals From Hydrochloric Acid Solutions, (February 2014), 37–41. https://doi.org/10.1080/08827508.2013.764875

Synergy 74

Hait, J., Jana, R. K., & Sanyal, S. K. (2012). Processing of copper electrorefining anode slime: a review. *Mineral Processing and Extractive Metallurgy*, *118*(4), 240–252. https://doi.org/10.1179/174328509x431463

JRC 2016 BREF Non-ferrous Metals Industries

JRC 2014 BREF Refining of Mineral Oil and Gas

Nagai, H., Shibata, E., & Nakamura, T. (2017). Development of methods for concentration and dissolution of Rh and Ru from copper slime. *Hydrometallurgy*, *169*, 282–289. https://doi.org/10.1016/J.HYDROMET.2017.01.004

Seisko, S., Aromaa, J., Latostenmaa, P., Forsen, O., Wilson, B., & Lundstrom, M. (2017). Pressure leaching of decopperized copper electrorefining anode slimes in strong acid solution. *Physicochemical Problems of Mineral Processing*, *53*(1), 465–474. https://doi.org/10.5277/ppmp170136

Synergy 75

Brenna, J. (1994). United States Patent 19 11 Patent Number: 45.

Cusano, G., Rodrigo Gonzalo, M., Farrell, F., Remus, R., Roudier, S., & Delgado Sancho, L. (2017). *Best Available Techniques (BAT) Reference Document for the Non-Ferrous Metals Industries - Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control).* https://doi.org/doi:10.2760/8224

Kagaya, S., Gemmei-ide, M., & Inoue, Y. (2014). Chelating Resins, 1–10. https://doi.org/10.1007/978-3-642-36199-9

Synergy 76 - NO REF

Synergy 77 - NO REF

Synergy 78

JRC 2017 BREF Production of Large Volume Organic Chemicals

Synergy 79

JRC 2017 BREF Production of Large Volume Organic Chemicals

Synergy 80

JRC 2017 BREF Production of Large Volume Organic Chemicals

JRC 2018 BREF Waste Treatment

Synergy 81

Brinkmann, Thomas; Santonja, Germán Giner; Yükseler, Hande; Roudier, Serge; Sancho, L. D. (2016). *Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control).*

Koch Modular. Retrieved from https://kochmodular.com/

Synergy 82

JRC 2017 BREF Large Combustion Plants

JRC 2014 BREF Production of Pulp, Paper and Board

JRC 2006 BREF Waste Incineration

Synergy 83

Feature, S., Article, O., & Management, W. (2009). Combustion kinetics of sewage sludge and combustible wastes, 203–207. https://doi.org/10.1007/s10163-009-0251-7

JRC 2017 BREF Large Combustion Plants

Synergy 84

Feature, S., Article, O., & Management, W. (2009). Combustion kinetics of sewage sludge and combustible wastes, 203–207. https://doi.org/10.1007/s10163-009-0251-7

JRC 2017 BREF Large Combustion Plants

Synergy 85

JRC 2014 BREF Refining of Mineral Oil and Gas

Synergy 86

JRC 2005 BREF Slaughterhouses and Animals By-products Industries

Synergy 87

JRC 2013 BREF Production of Cement, Lime and Magnesium Oxide

JRC 2014 BREF Production of Pulp, Paper and Board

JRC 2006 BREF Waste Incineration

Synergy 88

Brinkmann, Thomas; Santonja, Germán Giner; Yükseler, Hande; Roudier, Serge; Sancho, L. D. (2016). *Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control).*

Koch Modular. Retrieved from https://kochmodular.com/

Synergy 89

Hesas, R. H. (2014). An Approach for Water Cost of Cooling Water System in Oil Refinery, (January 2010). https://doi.org/10.3303/CET1021018

Synergy 90 - NO REF

Synergy 91

Chauhan, A., & Tassou, S. A. (2018). Waste Heat Recovery Technologies and Applications Waste Heat Recovery Technologies and Applications. *Thermal Science and Engineering Progress*. https://doi.org/10.1016/j.tsep.2018.04.017

Synergy 92

Chauhan, A., & Tassou, S. A. (2018). Waste Heat Recovery Technologies and Applications Waste Heat Recovery Technologies and Applications. *Thermal Science and Engineering Progress*. https://doi.org/10.1016/j.tsep.2018.04.017

Synergy 93

Chauhan, A., & Tassou, S. A. (2018). Waste Heat Recovery Technologies and Applications Waste Heat Recovery Technologies and Applications. *Thermal Science and Engineering Progress*. https://doi.org/10.1016/j.tsep.2018.04.017

JRC 2009 BREF Energy Efficient

JRC 2017 BREF Large Combustion Plants

Synergy 94

JRC 2009 BREF Energy Efficient

Synergy 95

Āriņa, D., Kļavenieks, K., & Burlakovs, J. (2014). The Cost-estimation of Mechanical Pre-treatment Lines of Municipal Solid Waste in Latvia, *32*(327). https://doi.org/10.2478/plua-2014-0009

JRC 2018 BREF Waste Treatment

Synergy 96

JRC 2018 BREF Waste Treatment

Synergy 97

JRC 2018 BREF Waste Treatment

Synergy 98

Chinyama, M. P. M. Alternative Fuels in Cement Manufacturing.

Hart, A. (2014). REVIEW PAPER - A review of technologies for transporting heavy crude oil and bitumen via pipelines, 327–336. https://doi.org/10.1007/s13202-013-0086-6

Usón, A. A., López-Sabirón, A. M., Ferreira, G., Astresa, E. L. (2013). Uses of alternative fuels and raw materials in the cement industry as sustainable waste management options, 23, 242–260. https://doi.org/10.1016/j.rser.2013.02.024

Psomopoulos, C. S., & Themelis, N. J. (2016). Use of waste derived fuels in cement industry. A review, (January 2018). https://doi.org/10.1108/MEQ-01-2015-0012

Synergy 99

International Renewable Energy Agency (2013). Production of Bio-Methanol.

JRC 2017 BREF Production of Large Volume Organic Chemical

Synergy 100

JRC 2017 BREF Large Combustion Plants